THE UNIVERSITY OF ALBERTA

DIVERGENT GROWTH IN LAKE WHITEFISH POPULATIONS FROM TWO EUTROPHIC ALBERTA LAKES

by

©

B. F. BIDGOOD

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF ZOOLOGY

EDMONTON, ALBERTA

FALL, 1972

Thesis
72F-8D

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled DIVERGENT GROWTH IN LAKE WHITEFISH POPULATIONS FROM TWO EUTROPHIC ALBERTA LAKES submitted by B. F. Bidgood in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

The ecology of lake whitefish populations in two eutrophic Alberta lakes was studied and compared to determine the limiting factors suppressing the growth rate of the one population of fish. The growth rate of individuals in the Pigeon Lake population has declined within the past twelve years whereas the growth rate of individuals in the Buck Lake population has remained relatively stable over the same period of time. The morphometry and limnology of the two lakes were comparable. Genetic control of growth did not appear to differ between these two populations of fish. Divergence in the growth pattern of these two populations began during the first winter in young-of-the-year fish. The predator-prey relationship in these two lakes differed. The one predator species in Pigeon Lake was reduced in numbers and a second predator species was virtually eliminated from the lake. As the number of shoreline cottages tripled in sixteen years, summer residents removed rooted, aquatic plants, spawning and recruitment habitat for northern pike, and selectively angled for the two predator species, walleyes and northern pike. Reduced predation likely caused suppression of the growth rate of the lake whitefish population by increasing the recruitment to both lake whitefish and other prey species and increasing the interspecific and intraspecific competition for food. Limited summer, residential development has occurred on Buck Lake within the same period of time. A predator-prey relationship conducive to producing a faster growth rate of Buck Lake whitefish has not, to date, been altered by man.

Differential growth rates in these two populations of whitefish had not altered the age of maturity; both sexes of both populations matured at about four years of age. Both populations of

whitefish spawned in both open water and under ice cover over a period of about four months in a wide range of water temperatures. The fecundity of the slower growing Pigeon Lake population was lower than that of the faster growing Buck Lake population but Pigeon Lake females produced larger eggs. The incubating water temperature controlled the incubation period of eggs to hatching. The larger Pigeon Lake eggs had similar incubation periods to the smaller Buck Lake eggs when subjected to the same temperature regime. The longer incubation period in both lots of eggs produced larger fish at hatching. Larger eggs did not produce larger hatching fish. During their first summer and winter young-of-the-year whitefish in both lakes fed mainly on zooplankton. The following spring these yearling fish began feeding on bottom fauna. Yearling and older lake whitefish in both lakes utilized the more abundant, available food supplies rather than selectively feeding on less abundant food items.

ACKNOWLEDGEMENTS

D. K. Berry assisted in the collection of the field data and in the construction, maintenance and collection of data from laboratory experiments for the duration of these studies. The following personnel assisted in various aspects of the data collection program both in the field and in the laboratory: D. S. Radford, L. Farrar, W. Church, B. Roach, B. Walton, G. Ash, B. Rippen, K. Dietz, R. Hart and Linda Walton.

The following members of the graduate committee offered constructive criticism and direction during the course of these studies: Dr. J. S. Nelson, Supervisor; Dr. H. F. Clifford; Dr. D. N. Gallup; Dr. J. R. Nursall, of the Department of Zoology, University of Alberta; and Dr. W. G. Evans, Department of Entomology, University of Alberta. Dr. G. H. Lawler, Freshwater Fisheries Institute, was outside examiner for the thesis defence. Dr. R. W. Davies assisted with the identification of the Hirudinea, Dr. G. B. Wiggins with the identification of the Trichoptera, R. J. Drake with the identification of the Mollusca and Dr. H. F. Clifford with the identification of the Ephemeroptera. Dr. S. B. Smith suggested the field of study and reviewed and commented on the manuscript in addition to C. E. Stenton and Dr. W. Mackay as well as the graduate committee members noted above.

R. D. Hunter, Cartography Section, Alberta Department of Lands and Forests coordinated the drafting of the final figures. Pat Lowry typed the manuscript and offered suggestions for change in the format of tables. My wife, Marlene, assisted by typing rough copies of and proof-reading the manuscript.

Financial assistance for this study that included wages, equipment purchases and operating expenses was provided by the Fish and Wildlife Division of the Alberta Department of Lands and Forests. A National Research Council grant to Dr. J. S. Nelson financed the construction of the closed-system egg incubation jars at the Department of Chemistry, University of Alberta.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Pigeon Lake ($53^{\circ}00'$N, $114^{\circ}05'$W) and Buck Lake ($53^{\circ}00'$N, $114^{\circ}45'$W) located in central Alberta, support lake whitefish, *Coregonus clupeaformis* (Mitchill), populations with dissimilar growth rates. Both these eutrophic, Alberta lakes have been commercially fished with gill nets since about 1920.[1] Detailed records of the commercial harvest of whitefish from these lakes are available since 1942. Both Pigeon and Buck lakes have been commercially fished with 5½ inch (13.97 cm) stretched mesh gill nets from 1942 to 1967. In 1968, the legal mesh size for the commercial fishery in Pigeon Lake was reduced to 4½ inch (11.43 cm) stretched measure to facilitate economical harvest of the commercial quota. The following year, a further reduction in the legal mesh size to 3½ inches (8.89 cm) was deemed necessary. Since 1942, the commercial harvest of lake whitefish from Buck Lake has remained relatively stable with continuous use of 5½ inch (13.97 cm) stretched mesh gill nets. Differential growth rates in whitefish populations have been documented by Kennedy (1963) and McCart (1965). The decline in the growth rate of the Pigeon Lake population and the sustained growth pattern of the Buck Lake population over the past twelve years presents an opportunity to investigate controlling factors in growth rates of lake whitefish populations by studying and comparing the ecology of these two populations of fish.

Biological data on the Pigeon Lake population published twelve years prior to the present studies enabled documentation of the change in the growth pattern of this population of whitefish. Miller (1956) conducted research on the Pigeon Lake lake whitefish population between 1942 and 1954

---

[1]Abstracts from Seminar Papers, Canada Department of Fisheries.

and published growth data on this population.

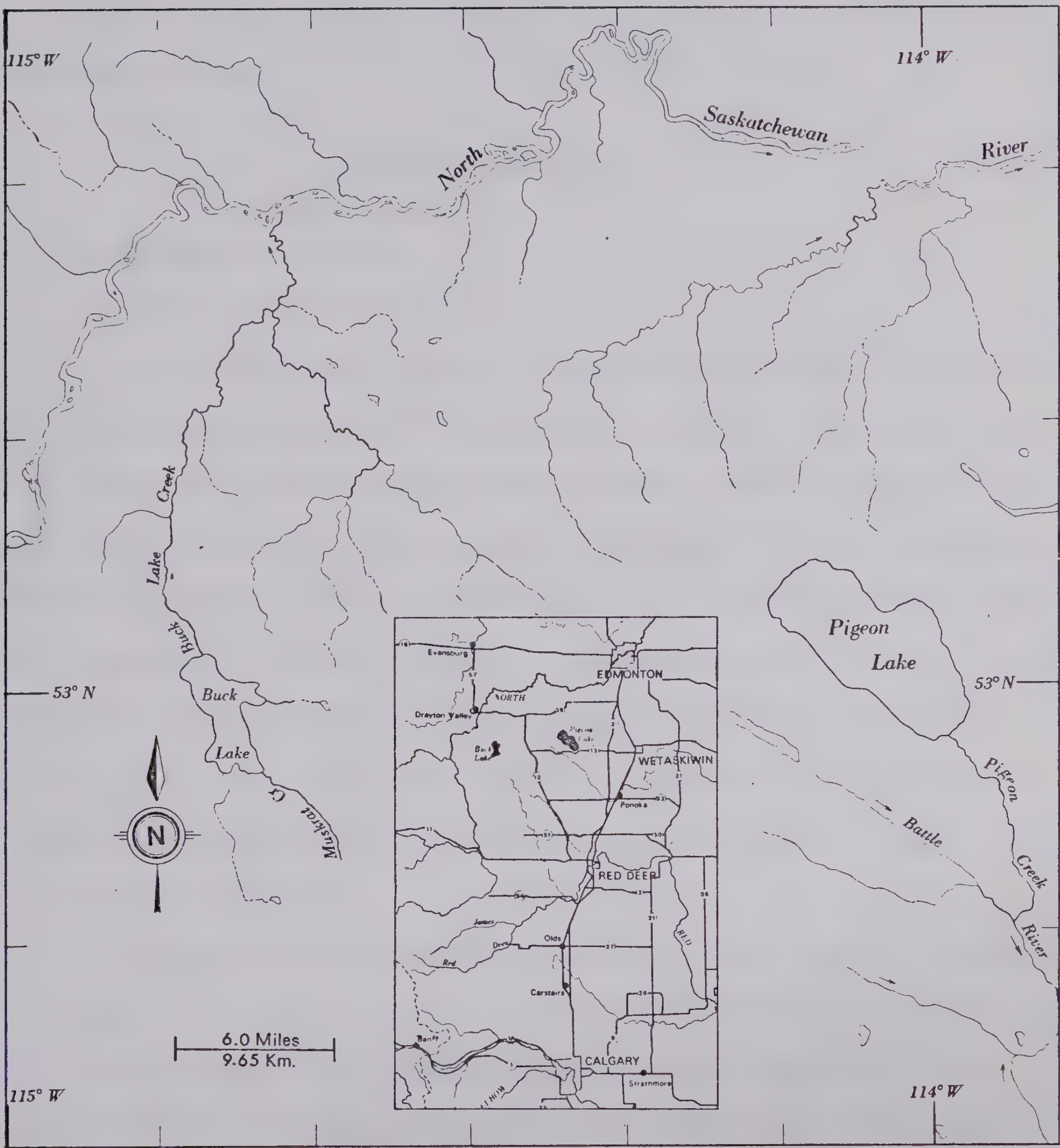
Many variables that could complicate an ecological comparison of the Pigeon and Buck Lake lake whitefish populations may be eliminated because of the similarity of these two lakes. Although Buck Lake is about one-quarter the size of Pigeon Lake, both lakes are located at the same latitude (53°00'N), are in the same major drainage basin, have similar bottom contours and support homogeneous, indigenous populations of lake whitefish.

Investigations into the ecology of these two lake whitefish populations that included both field studies and laboratory experiments were initiated in 1968 and terminated in 1972. This thesis presents a comparison of the spawning, growth rates, food habits and ecological habitat of these two populations of fish and describes when the growth rates of these two populations diverge. A thesis is presented on the cause of the decline of the growth rate of the Pigeon Lake populations and the maintenance of a similar growth pattern in the Buck Lake population over the past twelve years.

DESCRIPTION OF STUDY AREA

Pigeon Lake (47-01-W5) having a surface area of 23,699 acres (9590.99 ha) is about four times the size of Buck Lake with 6,144 surface acres (2486.48 ha) of water (Figure 1). Pigeon Lake has a maximum recorded depth of 30 feet (9.14 m) and Buck Lake has a maximum depth of 40 feet (12.19 m). Pigeon Lake has a mean depth of 20.5 ft (6.25 m) and Buck Lake has a mean depth of 20.3 ft (6.19 m). Both lakes are located in central Alberta on western Alberta Plains with bedrock of sandstone, shale and coal. The surficial deposits of the area are ground moraine, hummocky moraine and till. Pigeon Lake,

FIGURE 1. Pigeon and Buck Lake in the North Saskatchewan drainage system. The insert locates the study lakes relative to major Alberta cities and highways.



115° W
114° W
North
Saskatchewan
River
Creek
Lake
Buck
Buck
Lake
Muskrat Cr
53° N
53° N
Pigeon
Lake
Pigeon
Creek
Battle
River
N
6.0 Miles
9.65 Km.
115° W
114° W
Evansburg
EDMONTON
NORTH
Drayton Valley
WETASKIWIN
Ponoka
RED DEER
Olds
Carstairs
Banff
CALGARY
Strathmore

Figure 1

located at an elevation of 2,787 feet (849.48 m) drains through Pigeon Creek east to the Battle River and into the North Saskatchewan River at North Battleford, Saskatchewan. Buck Lake located at an elevation of 2,892 feet (881.48 m) drains through Buck Lake Creek north to the North Saskatchewan River.

MATERIALS AND METHODS

1. Physico-chemical Data

    1. Surficial Lake Sediments

Surficial lake sediments in Pigeon and Buck Lake were sampled with a weighted six inch (15.24 cm) Petersen dredge. The location and area of surficial lake sediments was recorded by making transects from the shore through the littoral zone to the deeper, silt portion around the perimeter of each lake. Each dredge sample was released on a tray and the percent of sand, silt, rubble and coarse and fine gravel (Lagler, 1959) was estimated. The designated composition of each sample was plotted on a contour map of the lake. Visual observations from the surface and by scuba diving supplemented the dredge sampling data.

    2. Water Quality

Two limnological stations were established, one in Pigeon Lake at a depth of 27 feet (8.23 m) and one in Buck Lake at a depth of 30 feet (9.14 m) (Figure 6). Both stations were over a surficial lake sediment of silt. Limnological data, gathered from both lakes within a three hour period on the same day, were collected monthly from November, 1970 to March, 1971 and bimonthly from May to October, 1971. Water temperatures were recorded at two foot (0.61 m) intervals from the bottom

to the surface with a thermister[2] having a marked cable and weighted probe. Water samples were collected on the same day at the same stations at one foot (0.30 m) below the surface, midwater and bottom with a modified Van Dorn water sampler, designed to be lowered vertically to the desired depth, stabilized in a horizontal position with a second line and closed. A metal apron affixed to the base of the sample bottle enabled it to be lowered vertically to the bottom and rotated horizontally to rest three inches (7.62 cm) off the bottom on the apron before a messenger, released from the surface, triggered the closing mechanism. The high and low range dissolved oxygen concentration of each water sample was determined with a Hach kit. Water samples were gathered on August 24, 1971 just below the surface at the limnological station on both lakes, placed in inert, sterilized containers, packed with ice in an insulated box and shipped to the Department of the Environment, Inland Waters Branch, Water Quality Division, in Calgary, Alberta within twelve hours of the time the samples were collected and analysed by atomic absorption spectrophotometry.

II. Biological Data

I. Lake Studies

Samples of fish were collected from each lake with gill nets. At each gill net set, the location, date and time of set, size (stretched measure), meshes deep, and length of each gill net, depth of set and water temperature at the set was recorded on catch record sheets. When the net set was pulled, the date and time of retrieval and the number of each species of fish captured in each mesh size of net were recorded on

---

[2] A.R.A. Model F7-3 hydrographic thermister. Applied Research, Austin, Texas.

the same catch record sheet. Each set of a gang of nets was assigned a catch record number.

Sampling of the catches was performed in a mobile laboratory (Appendix A) that was moved from one lake to the other during the netting operations. A maximum of 30 lake whitefish were sampled from each mesh size and the fork and total length in millimeters, weight to the nearest gram and sex and maturity of each fish was recorded on record sheets. Each fish was assigned one of five categories of maturity according to the appearance of the gonads. Immature fish had only a ribbon of gonad tissue and were not sexed. Maturing fish had definite gonad development. Sex could be determined by the appearance of eggs in the female gonad or the white color of the male gonad. Mature fish had larger gonads that occupied the entire length of the coelomic cavity but did not freely emit eggs or sperm through the genital opening when external pressure was applied to the specimen. Ripe individuals freely emitted their genital products with a minimum of pressure to the exterior of the fish. Spent individuals had flaccid gonads with the majority of the eggs absent in females and a reduced size of the testes in males.

The data from each fish sampled were coded with a sample number that included the catch record number of the gill net set that captured the sample. Scales were removed from the left side of the fish beneath the dorsal fin and above the lateral line and placed in scale envelopes stamped with the lake, date, catch record and sample number for age determination. About six scales from each scale envelope were placed separately on one acetate slide, covered with a second slide, secured in place by bonding the four edges of the two slides on a hot

plate and read on an Eberbach Microprojector. Scales were aged independently of the fish sample data. Each annulus was determined by the presence of the first complete circulus that followed compacted, incomplete circuli.

The feeding habits of Pigeon Lake lake whitefish ranging in size from 101 to 500 mm fork length and Buck Lake fish ranging in size from 201 to 700 mm were examined and compared over a twelve month period. The stomach of each fish sampled was preserved in a jar with ten per cent formalin and labelled with the date, catch record number and 25 mm size class range that included the fish from which the stomach was extracted. The volume contribution of the various food items to the relative fullness was estimated using a technique described by Thompson (1959). The stomach of each individual sample was removed intact and the relative fullness estimated and assigned a value that ranged from 0 to 20. An empty stomach was assigned a value of 0 whereas a full stomach was assigned a value of 20. The volume contribution of food items to the assigned relative fullness was estimated. The feeding habits of young-of-the-year fish were documented using the same technique.

Stomachs of white suckers, *Catostomus commersoni* (Lacépède), walleye, *Stizostedion vitreum vitreum* Mitchill, and northern pike, *Esox lucius* Linnaeus were placed in separate jars for each species and preserved with ten per cent formalin. Each jar was labelled with the appropriate catch record number and the stomachs were later examined for identification of food items.

The species of fish present in each lake was determined by gathering samples of fish with five types of gear; gill nets, both monofilament nylon and braided nylon that ranged from three-quarter inch

(1.91 cm) to one and one-half inch (3.81 cm) stretch measure monofilament and two inch (5.08 cm) to five and one-half inch (13.97 cm) 210/3 braided nylon; a fifty foot (15.24 m), one-quarter inch (0.63 cm) mesh beach seine; a six foot (1.83 m) brail net of one-half inch mesh (1.27 cm); a meter trawl with a 00 mesh bucket; a 16 foot (4.88 m) outboard trawl with a one-half inch (1.27 cm) mesh liner in the cod end. Gill net sets were made in both the littoral and limnetic zones of the lakes. Seine hauls were made during the day and after dark around the perimeter of both lakes. Brail net casts were made from protruding docks on both lakes where visual observations of fish were made. Meter trawls were made in the littoral portion of the lakes while outboard trawl samples were collected in the limnetic portion of each lake.

The three major tributary streams flowing into Buck Lake (Figure 3) were examined for walleye spawning migrations immediately after the ice left these tributary streams in the spring. A five foot (1.52 m) square-framed fyke net was set across the largest stream to capture upstream migrants and was examined daily. Gill nets were set in the minor tributary streams and the species of fish captured was documented. When the ice left Buck Lake in the spring, gill net sets and visual observations were made in the lake to document spawning grounds for walleyes.

Gonad development data on lake whitefish were collected bimonthly from January to March and from May to October, 1970. A minimum sample of 30 female fish was collected on each sampling date from each lake. Scales were removed for age determination and the total weight of the fish to the nearest gram and the total weight of both gonads to the nearest tenth of a gram was recorded for each sample. Only

mature fish with four or more completed annuli were used in the analysis. Fish with atypical gonad development or a single gonad were not used in the analysis.

Areas of concentrated lake whitefish spawning were documented with gill net sets at various locations in both Pigeon and Buck Lake during the open water spawning period (October to November). The location of and water temperature at each gill net set was recorded. Spawning grounds were determined by the presence of ripe and spent male and female fish in the same gill net set, the absence of immature fish in these gill net sets, the presence of tubercles and the occurrence of nuptial displays (Hart, 1930) on the surface at night. The most active spawning periods on these beds was determined by the ratio of spent and mature to ripe male and female fish in these gill net samples from the spawning beds.

The duration of spawning in Pigeon and Buck Lake was determined by setting gill nets on the spawning beds in the open water and through ice cover from mid-September to the end of January. Spawning was designated as taking place when ripe female fish occurred in these gill net samples.

The oviduct egg size of lake whitefish was determined by selecting adult (IV+ and older) fish from gill net samples from the spawning beds of both lakes. Oviduct eggs were eggs that were separate from one another in the ovary and were not attached to the gonad by mesentery (Fisher, 1963) and had not yet been released by the fish. The average size of a sample of fifty eggs was considered a more accurate measurement of the oviduct egg size than measuring individual eggs because of the elliptical shape of these unhardened eggs (Higham and

Nicholson, 1962). Fifty eggs were extracted from each of the anterior, mid and posterior portion of the left gonad, placed side by side in a wetted, acrylic, V-shaped trough with a stainless steel ruler affixed to one side of the trough and measured to the nearest millimeter. The average size of an egg was calculated for each of the 30 samples from each of three locations of the gonad.

The fecundity of the Pigeon and Buck Lake lake whitefish populations was determined by weighing a sample of 50 eggs from each of the anterior, mid and posterior portion of the left gonad of 30, ripe fish from each lake to the nearest hundredth of a gram. After differences in the weights of the eggs from the three locations was found to be nonsignificant, the mean weight of the 90 samples from the 30 fish from each lake was used to calculate a mean for each population. The mean weight of 50 eggs from each population was used to estimate the number of eggs in the weighed gonads of 60, mature, sampled fish from each lake.

The size and growth rate of young-of-the-year lake whitefish in Pigeon and Buck Lake were determined by recording the total length and fork length in millimeters and the weight to the nearest tenth of a gram of samples of fish captured during the open water period in a 16 foot (4.88 m) midwater trawl with a one-half inch (1.27 cm) cod end liner and with monofilament nylon gill nets. All fish captured on a given date in each lake were sampled. Scales were removed from each fish and read to calculate the age of each individual. Monofilament nylon gill nets of three-quarter inch (1.91 cm), one inch (2.54 cm) and one and one-half inch (3.81 cm) stretched mesh size were set to obtain samples through the ice of both lakes.

Samples of yearling and older lake whitefish were collected with gill nets from Pigeon and Buck Lake in the latter two weeks of September, 1970 and 1971. Gill nets of 1½ (3.81 cm), 2 (5.08 cm), 4 (10.16 cm), 4½ (11.43 cm), 5 (12.70 cm), 5½ (13.97 cm) inch stretched measure were set to acquire the samples of lake whitefish from Buck Lake whereas 1½ (3.81 cm), 2 (5.08 cm) and 3½ (8.89 cm) inch stretched measure were used in Pigeon Lake each year. Not less than 30 lake whitefish of each year class were sampled from each lake each year. The fork length and total length in millimeters and weight to the nearest gram was recorded for each fish sampled. Scales were removed for age determination and aging was completed on location with a Tri-simplex projector. Nets were reset until the required sample of 30 fish of each age class from each lake was obtained. In 1971, the sex of the mature fish was recorded and used in the computation and comparison of the weight-length ratio (Rounsefell and Everhart, 1960) of immature, mature female and mature male components of the samples from both lakes.

The age of maturity of individuals of both populations of lake whitefish was determined from samples captured in gill net sets made between October and January on and off the known spawning beds. At this time of year, immature and maturing fish could be readily distinguished from mature, ripe and spent fish by the appearance of the gonads. An immature fish had no sex products visible in the small, ribbon-like gonad. A maturing fish could be sexed but the size of the gonad and the sex products indicated the fish would not spawn in the current spawning season. Mature fish had relatively larger gonads and sex products that would be released in the current spawning season.

Ripe fish liberated their sex products when subjected to a minimum of external pressure. Spent fish had large, flaccid gonads with the bulk of the eggs or sperm emitted. Scales were removed from each fish sampled for age determination. The ratio of immature and maturing fish to mature, ripe and spent fish of both sexes in each age class was determined for the samples from both lakes.

Fifty adult lake whitefish from Pigeon Lake and 50 from Buck Lake were collected and examined for morphometric and meristic data. The fork length, total length and weight were recorded for individuals of each sample. The number of gill rakers, including rudimentary rakers, on both the upper and lower limb of the first gill arch on the left side of each specimen was enumerated. The length of the longest gill raker occurring mid-way between the upper and lower limb of the same gill arch was measured to the nearest tenth of a millimeter with a machinist's dial reading caliper.

The standing crop of bottom fauna in Pigeon and Buck Lake was sampled with a six inch (15.24 cm) Ekman dredge in each of three surficial lake sediments. With the exception of November, each lake was sampled monthly from July to March, 1971 and bimonthly from May to June, 1971. Both lakes were sampled on two consecutive days. Three samples were taken in a silt, three in a sand and three in rubble substrate of each lake (Figure 6). During the open water period in the lakes, each dredge sample was released into a screen bottom pail of 30 meshes to the inch (12 meshes to the centimeter) with a gap of 0.8 mm between the 0.3 mm wire. The contents of the screen bottom pail were washed into a twenty pound weight plastic bag held inside a second, similar bag. A code

number was placed in the bag before it was sealed. When the bottom samples were collected through the ice, the contents of the Ekman dredge were released and washed into a plastic pail. The contents of the pail were washed into two 20 pound weight plastic bags. Each sample was coded and sealed. On shore in a heated building, the contents of the plastic bag were washed through the screen bottom pail and the contents of the screen bottom pail were washed into two new plastic bags. The washed contents of the plastic bags were placed in a white enamel pan and the invertebrates were removed from the pan with fine tweezers and placed into coded vials with 70 percent ethanol. Each code number related to the following information recorded in a bottom sample record book: lake, date, surficial lake sediment and depth of water at the sampling station. The invertebrates in each sample were enumerated and identified using Ward and Whipple (1963), Bird (1968), Pennak (1953), Usinger (1963) and Davies (1971).

The standing crop of plankton was sampled monthly excluding November and April, from June, 1970 to June 1971 at the limnological stations on Pigeon and Buck Lake (Figure 6). Both lakes were sampled within the same two days of the month. One sample was collected six inches (15.24 cm) from the bottom, one at midwater and one at the surface of each station with a modified Van Dorn water bottle that was lowered vertically to the desired depth, stabilized in a horizontal position and closed with a messenger from the surface. Each sample collected a volume of 3,270 ml ± 10 ml of water. In open water, the contents of the water bottle were poured through a 12 cm Wisconsin plankton net with 20 mesh nylon bolting cloth having 173 threads to the inch in both the upper net and straining bucket. The inside of the net was then washed

with distilled water to force any adhering plankton to the bucket. The contents of the plankton bucket were washed with a 70 percent ethyl alcohol solution into a coded vial. When samples were collected through the ice, the contents of the Van Dorn water bottle were poured into two twenty pound weight plastic bags, one inside the other, and sealed. On shore in a heated building, the contents of the bags were washed through the plankton net. The inside of the net was washed with distilled water and the contents of the bucket washed with ethanol solution into coded, preserving vials. Each vial code number related to the following data recorded in a plankton sampling data book: lake, date, location and depth of sample.

After the zooplankton had settled in the preserving vial, excess preservative was removed with a suction tube having the end covered with 20 mesh bolting cloth to prevent removal of specimens. The concentrated sample was washed with 99 percent ethanol into a five centimeter diameter petri dish having masked edges and numbered octants etched into the base of the dish. The sample was covered with a solution of 75 percent glycerin in ethanol, agitated to permit random distribution of the zooplankton and exposed to the air overnight to permit the ethanol to evaporate and the specimens to become stabilized in the viscous glycerin. The zooplankton in every second octant was identified using Brooks (1957) and Pennak (1953, 1963) and enumerated. The total number of specimens of each species in the four octants was multiplied by two to derive the total number in the sample.

2. Laboratory Experiments

Eggs from ripe lake whitefish captured in gill nets set on the

spawing beds of Pigeon and Buck Lake in the latter part of October, 1970 and 1971, were stripped and fertilized. In 1970, eggs from Pigeon Lake fish were hardened in both Pigeon Lake and Buck Lake water and eggs from Buck Lake fish were hardened in both Pigeon and Buck Lake water. The eggs from at least four female fish from each lake were stripped into a clean, plastic bucket, out of direct sunlight, and fertilized using the dry method with milt of a minimum of six male fish. The eggs were allowed to remain in the milt at least five minutes before they were washed three times with the water the eggs were to be placed in for experimentation. The eggs were then placed into a four quart (3.79 l) glass jar with Pigeon or Buck Lake water. This technique was repeated until four jars of eggs were obtained, two in Pigeon Lake water and two in Buck Lake water. The four jars were packed with ice in a styrofoam cooler, covered and allowed to stand to harden. After standing for at least two hours, the eggs were transported to the laboratory in Edmonton. In the laboratory, the eggs were placed in troughs containing the same Pigeon or Buck Lake water in which the eggs were hardened. Eggs were also placed into a closed, jar-culture incubation system in each trough containing filtered, lake water from Pigeon or Buck Lake. In 1971, the same technique of collecting and transporting the eggs was used, but the eggs from both lakes were hardened and incubated in Pigeon Lake water.

The average diameter of the Pigeon and Buck Lake eggs hardened in the Pigeon or Buck Lake water was calculated by placing 30 samples of 50 eggs each from each water bath in line on an acrylic plastic V-shaped trough with a stainless steel millimeter ruler affixed to the base. The average diameter of Pigeon and Buck Lake eggs incubated in the different water baths was again calculated when the eggs eyed.

The hardened eggs from Pigeon and Buck Lake lake whitefish were incubated in three 84 (213.36 cm) x 24 (60.96 cm) x 22 (55.88 cm) inch rectangular, fiberglass, insulated "Living Stream"[3] recirculation troughs, with a 3950 B.T.U. frigid unit driven by a 1/3 h.p. motor, and a Min-o-cool compressor with a 1/12 h.p. circulation motor (Appendix B). The compressor was controlled by an auxillary Yellow Springs Instruments Thermistemp temperature control that maintained a trough water temperature ±0.04°C the desired temperature. An activated charcoal filter for nitrogenous waste removal, and an open pore foam rubber filter, for solid waste removal, was placed at the base of each recirculation trough. Trough water temperatures were monitored with a Digitex Thermister that recorded water temperatures in each trough to the nearest 0.01°C. Eggs from Pigeon and Buck Lake were placed in separate, covered trays in each of the three troughs. The eggs in the trays were treated with a concentration of one gram of refined Malachite green (1:200,000) for one half hour each week until the eggs eyed to control white spot disease (Wolf, 1970). In each treatment, the trough filters were removed and the weighed chemical added to the water. The filters were replaced in one-half hour to remove the malachite green from the trough water.

A series of nine, closed system, incubation jars were suspended in the water of the recirculation trough by an eight centimeter thick closed-pore styrofoam cover that floated on the surface of the water of the trough (Appendix B). Each jar was constructed from a Buchner funnel with a D-porosity filter (ASTM 10-20μ) of 10 cm in

---

[3] S.S. Filtration and Development Co. Ltd., 1429 Speers Rd., Oakville, Ontario.

width, 14 cm in depth[4] (Appendix C). An extension of 16 cm of glass tubing of the same width and gauge as the Buchner funnel was fused to the funnel giving the incubation jar a total depth of 30 cm. A glass lip of 14 cm in diameter was fused to the incubation jar, four cm from the top of the jar that enabled the jar to be suspended in the controlled temperature water bath by the styrofoam floating on the surface of the trough water. A compressed air line that passed through a Model S-11 Ozonizer[5] that delivered 0.8 mg O_3/hr was connected to the base of each incubation jar to control fungi and bacteria. The volume of air and ozone gases delivered to each jar was controlled by a Gilmont Micrometer Capillary Valve. The air and ozone mixture passed through the base of the Buchner funnel and was dispersed by the D-porosity filter into fine bubbles that passed through the water column in the jar and rolled the eggs. Each jar was covered with a 30 cm long, 30 mm wide acrylic plastic tube attached to a lid that excluded light, reduced evaporation at the surface of the water column and replenished the water lost in the incubation jar due to evaporation (Appendix C). A mechanism was attached to the base of each reservoir of distilled water to control the water level in the incubation jar. The control mechanism permitted air to enter the reservoir and allowed distilled, reservoir water to enter the incubation jar to the point where the supply of air to the reservoir was stopped. The trays of eggs in each trough were covered and the exposed portions of the incubation jars were painted black to exclude light from the incubating eggs.

---

[4]Ace Glass Ltd., Vineland, New Jersey - Cat. No. 7186-58.

[5]Conacto Limited, Ste 385, 4180 Courtrai Ave., Montreal 24, P.Q.

A glass tube attached to a vacuum line and inline filter was used to remove the dead eggs and filter the water in the closed jar cultures (Appendix D). Suction on the line was created by finger pressure on a hole in the glass tube. Dead eggs and incubation water were drawn through the tube into the first quart sealer where the dead eggs were retained in a screened area below the incoming line. The water continued through a Gelman pleated filter capsule of 3.0μ porosity that removed organic debris. The filtered water was collected in a second quart sealer attached to the vacuum line. After the dead eggs were picked from the jar culture, the filtered water collected in the second quart sealer was returned to the incubation jar.

In 1970, Pigeon and Buck Lake lake whitefish eggs were placed in trays and jars of one trough controlled at 2°C for the duration of the experiment, a second trough controlled to 4°C for the duration of the experiment and a third trough controlled to 2°C to the eyed-egg stage, raised at the rate of 0.5°C per week to 4°C and maintained at that temperature for the duration of the experiment. The incubation period in days to the eyed-egg stage was noted for both the jar and tray culture technique of each of the three experiments and the number of fish hatching daily in both jars and trays of the three troughs were recorded for the duration of the experiment.

In the 1971 experiments, Pigeon and Buck eggs, hardened and incubated in Pigeon Lake water, were reared in two troughs controlled at 2°C until January 4, 1972. After this date, the incubation water temperature of one experimental trough was raised at the rate of 0.5°C per week to 4°C and maintained at that temperature while the second

trough water temperature was maintained at 2°C for the duration of the experiment. The number of fish hatching daily from jars and trays was recorded for each of the controlled incubation temperature experiments. A recording thermometer (Ryan D-30) was placed through the ice on the lake whitefish spawning beds in Buck Lake to record actual egg incubation water temperatures.

Samples of young-of-the-year (y-o-y) Pigeon and Buck Lake lake whitefish from the experimental troughs were placed in four, ten gallon (37.85 l) aquaria the same day of hatching, reared under the same ambient temperature (12.5 to 15°C) and with the same food supply and photoperiod. A known number of hatched Pigeon and Buck Lake fish were placed in separate aquaria on the same day. The fish, in aquaria equipped with a charcoal fiberglass filter and an aeration stone, were fed twice daily with brine shrimp, *Artemia salina*, at the rate of 0.05 gm food per fish per feeding. A weighed amount of artemia eggs was placed in a separate incubation cell with brine solution that was suspended in a circulating water bath controlled to 80°F (26.7°C). The brine solution and eggs in each cell were aerated and circulated by air diffusing through an open-pore styrofoam base of each cell (Appendix E). The following day after a minimum of 18 hours of incubation, the contents of one cell were strained through a fine mesh cloth in a funnel and washed and concentrated with distilled water into the base of the cloth in the funnel. The cloth containing the hatched artemia and unhatched eggs was washed into the appropriate aquarium. The fish were allowed to feed at least one hour with the air supply turned off. Samples of 30 Pigeon Lake and 30 Buck Lake fish were removed and measured for total length after 57 rearing days. A second sample of 30 fish from each

lake was removed and measured after 60 to 63 rearing days.

Student's "t" test for unpaired observations and unequal variances was employed in the statistical comparison of any two means of samples with equal and unequal observations. The least squares method was employed in the calculations of regression equations. The slopes of two regression equations were compared to determine if the lines were estimates of the same population (Steel and Torrie, 1960).

III. Morphometry

1. Depth Contours

The depth contour maps from hydrographic soundings made by the Alberta Department of Water Resources for Pigeon Lake in September of 1961 and Buck Lake in September of 1964, were used in this study. Depths recorded during the present studies were comparable to those of the supplied contour maps.

2. Rooted, Perennial Aquatic Plants

The locations of the rooted, perennial aquatic plants in the littoral zones of Pigeon and Buck Lake were documented in July, 1969 and plotted on maps of both lakes. The survey was conducted by boating around the perimeter of each lake and plotting the location, depth and species of aquatic plants on a map. Samples of the species of plants were collected, dried, pressed and identified using Moss (1959) and Fernald (1950).

3. Cottage Development

The cottage development on shoreline lots in Pigeon and Buck Lake was determined by magnification of one inch (2.54 cm) to 1320 feet (402.34 m) aerial photographs of the perimeter of each lake. The number

of shoreline cottages on both lakes were enumerated from aerial photographs taken in 1950 and again from aerial photographs taken in 1966.

RESULTS

1. Physico-chemical Data

The bottom of Pigeon Lake slopes from the shore to a maximum depth of 30 feet (9.14 m) of water located in the central portion of the lake (Figure 2). Areas of boulder and rubble bottom are located at localized areas around the perimeter of the lake in water depths shallower than 20 feet (6.10 m). The lake sediment in the deeper portion of the lake, greater than 20 feet (6.10 m) of water, is mainly silt. About 16.6 percent of the surface area of the lake has a bottom substrate composed of boulders, rubble and sand. The lake has 25.8 miles (41.51 km) of shoreline with a shore development ratio (Welch, 1948) of 1.19. Pigeon Lake has small, intermittent drainage systems into the lake and no surface discharge of water from the lake occurred during the course of these studies.

The bottom of Buck Lake slopes from the shore to a maximum depth of 40 feet (12.19 m) located in the central portion of the lake (Figure 3). The areas of boulder and rubble bottom are located at localized areas around the perimeter of the lake in water depths of 25 feet (7.62 m) or less. The area of the lake deeper than 25 feet (7.62 m) has a surficial lake sediment composed mainly of silt. About 15.4 percent of the surface area of the lake is located over a boulder, rubble, and sand surficial

FIGURE 2. Location of surficial lake sediments in Pigeon Lake. Depth contours are presented in feet. Permanent (solid line) and intermittent (broken line) drainage systems are indicated by arrows.

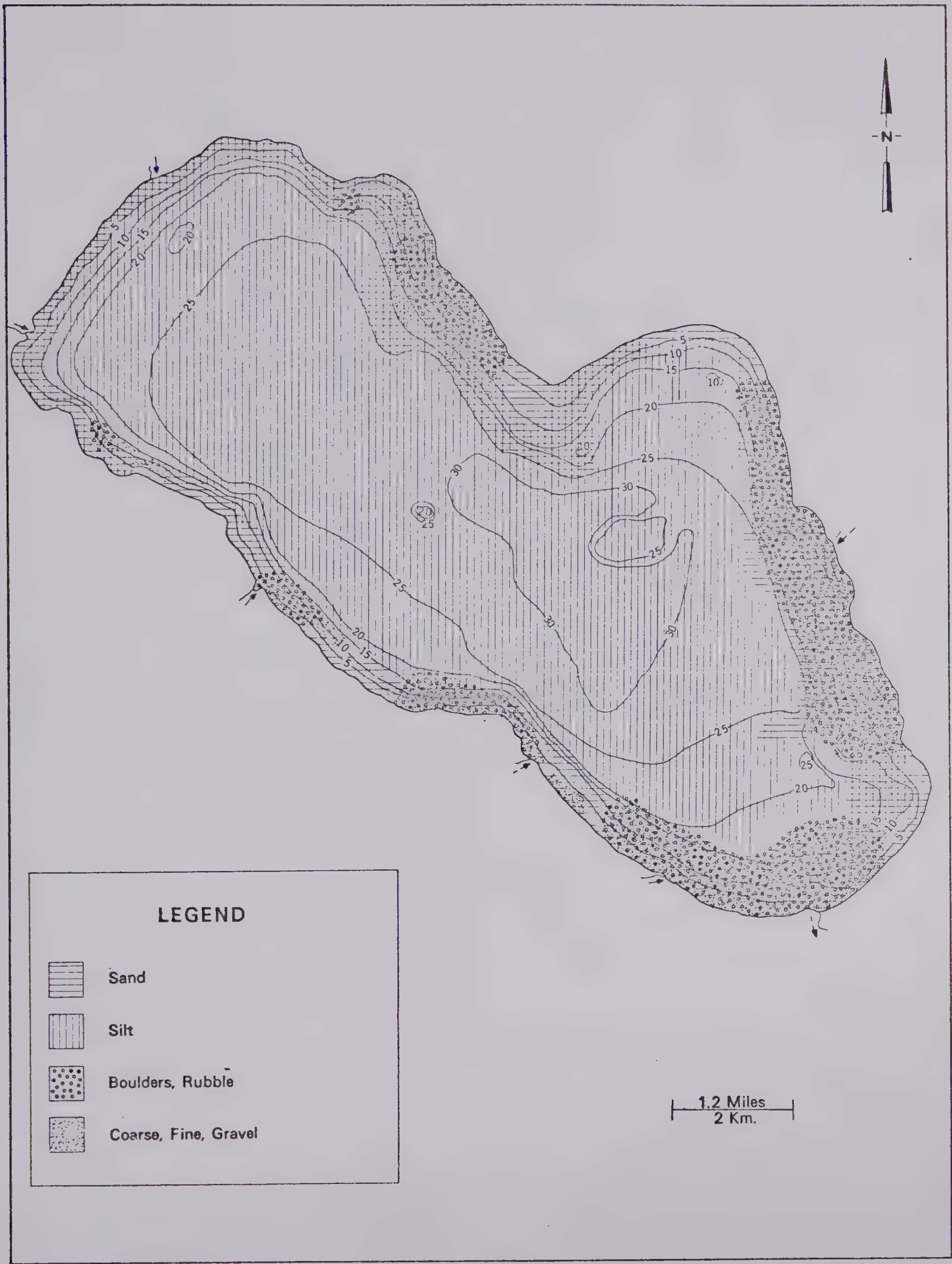

N
5
10
15
20
25
30
LEGEND
Sand
Silt
Boulders, Rubble
Coarse, Fine, Gravel
1.2 Miles
2 Km.

Figure 2

FIGURE 3. Location of surficial lake sediments in Buck Lake. Depth contours are presented in feet. Permanent (solid lines) and intermittent (broken lines) drainage systems are indicated by arrows.

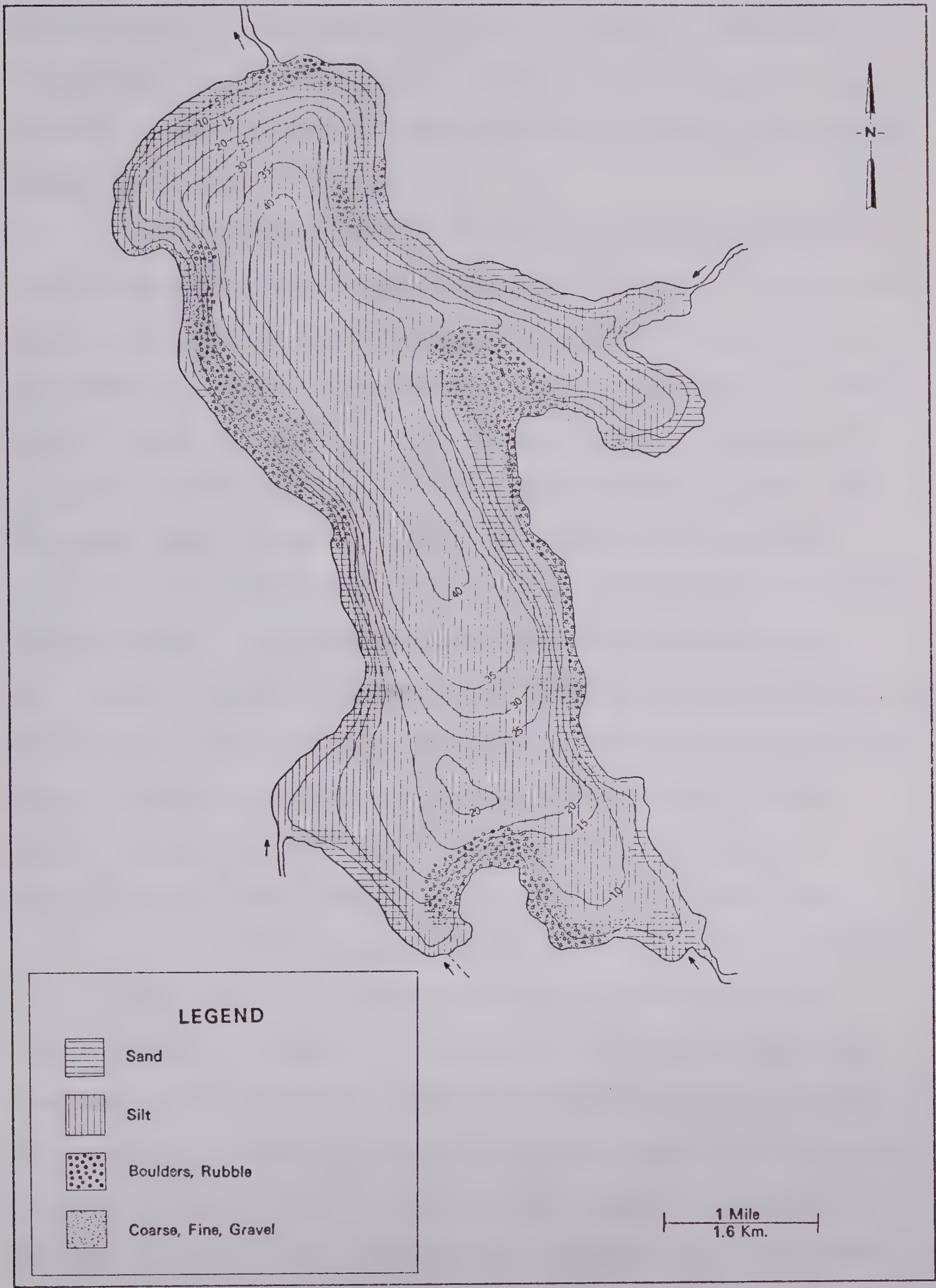

N
LEGEND
Sand
Silt
Boulders, Rubble
Coarse, Fine, Gravel
1 Mile
1.6 Km.
5
10
15
20
25
30
35
40

Figure 3

lake sediments. Buck Lake has 21.8 miles (35.08 km) of shoreline with a shore development ratio (Welch, 1948) of 1.98. The lake has three permanent drainage systems discharging into the lake and one permanent, dammed outlet from the lake.

A temperature regime in Buck Lake that is more favorable to growth than that of Pigeon Lake could account for the different growth rates of the two lake whitefish populations. However, Pigeon and Buck lakes have similar water temperature regimes (Figure 4). Thermal stratification did not occur in either lake during the study period since both these shallow lakes were frequently mixed by summer winds. A narrower range between the surface and bottom water temperature occurred in Pigeon Lake than in Buck Lake since Buck Lake, the smaller lake of the two, is more protected from the wind than Pigeon Lake. This reduced mixing by the wind in Buck Lake accounted for the formation of ice on the lake in the fall from five to seven days ahead of Pigeon Lake. The ice left Buck Lake five to seven days ahead of Pigeon Lake in the spring. Buck Lake had a greater discharge of warm, surface, spring, runoff water into the lake than did Pigeon Lake.

Low dissolved oxygen concentrations in Buck Lake during the winter could restrict the size of the population in Buck Lake by causing a partial winter kill and reducing intraspecific competition and increasing growth rates. Winter kill could be reduced or absent in Pigeon Lake. However, the dissolved oxygen concentrations in Pigeon Lake were similar to that of Buck Lake when compared over a period of one year (Figure 5). The concentration in Pigeon Lake on the bottom was lower than that of Buck Lake during the winter months (Jan. to March). No marked chemical stratification in either lake was

FIGURE 4. Water temperatures at the surface and bottom of Pigeon and Buck Lake. Recordings were made in each lake on the same day. The period of ice cover on both lakes is indicated.

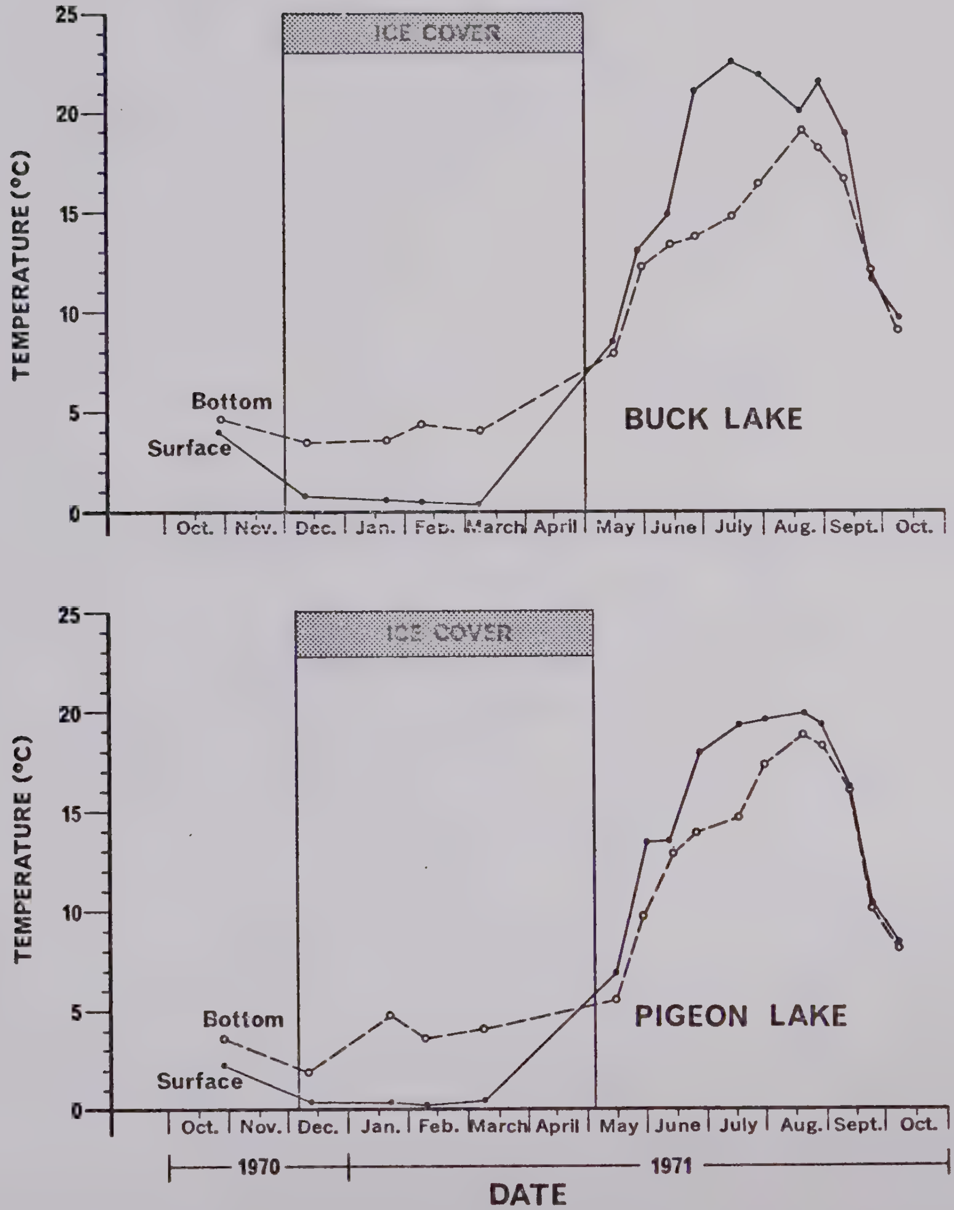

ICE COVER
TEMPERATURE (°C)
Bottom
Surface
BUCK LAKE
Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct.
ICE COVER
TEMPERATURE (°C)
Bottom
Surface
PIGEON LAKE
Oct. Nov. Dec. Jan. Feb. March April May June July Aug. Sept. Oct.
1970
1971
DATE

Figure 4

FIGURE 5. Dissolved oxygen concentrations of Pigeon and Buck Lake water sampled one foot below the surface and six inches from the bottom of each lake on the same date. The period of ice cover in both lakes is indicated.

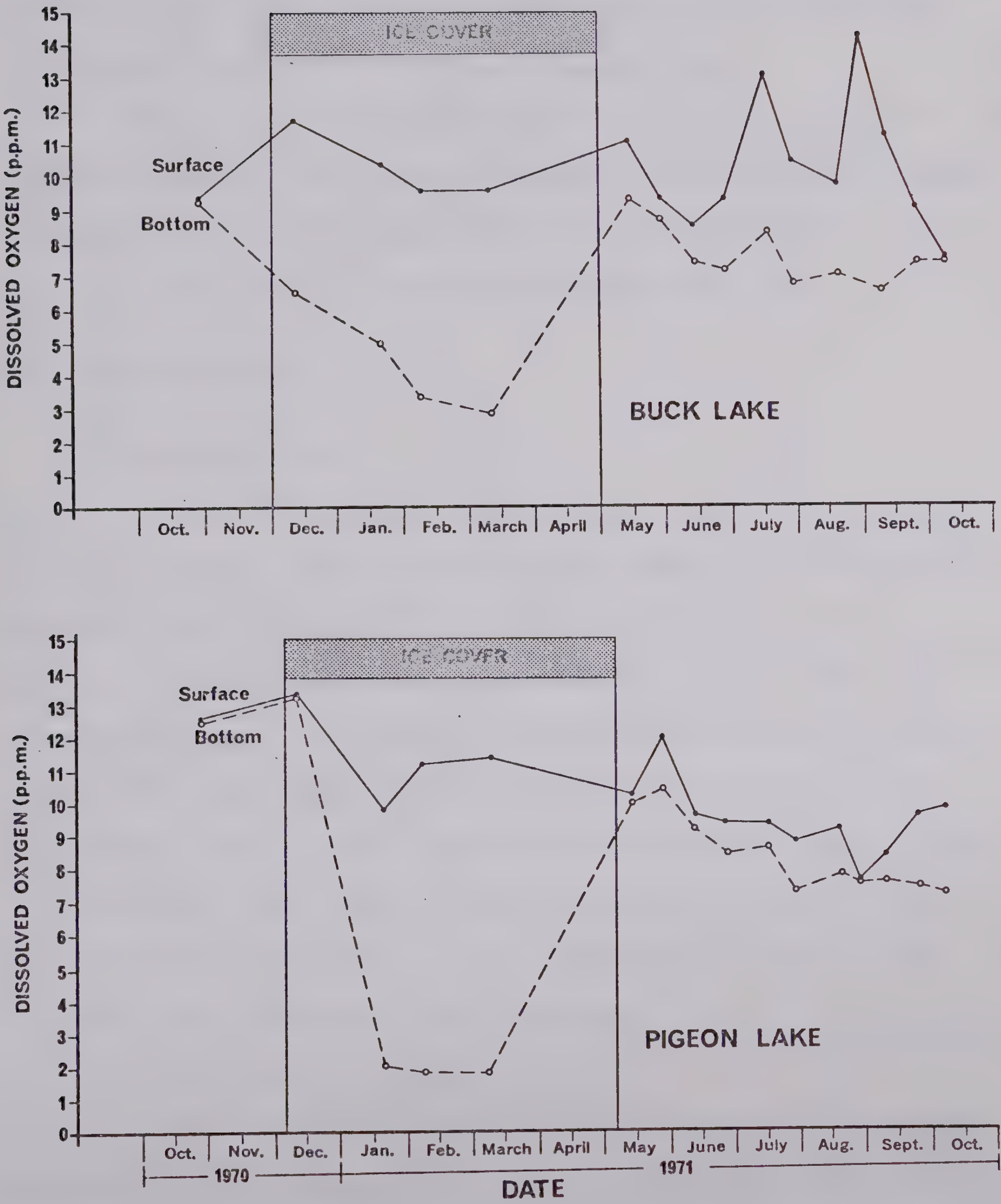

ICE COVER
DISSOLVED OXYGEN (p.p.m.)
Surface
Bottom
BUCK LAKE
Oct.
Nov.
Dec.
Jan.
Feb.
March
April
May
June
July
Aug.
Sept.
Oct.
ICE COVER
DISSOLVED OXYGEN (p.p.m.)
Surface
Bottom
PIGEON LAKE
1970
1971
DATE

Figure 5

recorded during the period of study. The dissolved oxygen concentrations of the bottom of Pigeon Lake under ice cover were lower than those of Buck Lake. Both lakes were chemically mixed in October prior to the formation of ice cover. Dissolved oxygen concentrations would not likely cause winter kill in either of the study lakes.

The results of the chemical analysis of water samples collected from the surface of both lakes on the same day are presented in Appendix F. Further sampling on a yearly basis at different depths is necessary for valid comparison of the water chemistry of these lakes.

II. Biological Data

1. Lake Whitefish

A total of 4,455 lake whitefish were sampled from the catches in Pigeon Lake and 3,121 lake whitefish were sampled from the catches in Buck Lake during the course of these studies. The lake whitefish populations in both lakes approached a 50:50 sex ratio. Mature fish spawned every year since no gonad reabsorption was observed or retention of sex products was noted in whitefish captured after January during the course of these studies. Sexual dimorphism was not evident in the total length and fork length of a given age class of fish from either population when the means of the partitioned sex components of each age class sample were statistically compared.

a. Growth of Individuals

Annulus formation occurred in April on both lakes before the ice cover left the lakes coincident with the warming of the lake water. The discharge of warm water from the surrounding land into the lake raised lake water temperatures and the whitefish became more active.

A reduction in the growth rate of individuals of the Pigeon Lake lake whitefish population has occurred since 1956 (Table I). On comparing the growth data from the present studies with the weighted means of four age classes of fish captured in the fall of 1951 to 1954 inclusive (Miller, 1956), the four age classes of fish in 1956 were larger than the same age classes in 1970. The Buck Lake population of the same age classes was larger than that of Pigeon Lake in both 1956 and 1970. Detailed statistical computations of these data are presented in Appendix G.

A divergence in the growth pattern of Pigeon Lake and Buck Lake lake whitefish occurs before the fish form their first annulus (Table II). The Buck Lake samples of six age classes of fish were larger than that of the same age classes of fish from Pigeon Lake in both the 1970 and 1971 samples. Differences in the means of samples of individual age classes from the same lake between the two years are obvious. Detailed statistical computations of these data are presented in Appendix H.

The weight-length ratio of Buck Lake samples of lake whitefish taken in the last two weeks of September were higher than that of the Pigeon Lake samples taken during the same period of time (Table III). Buck Lake mature males and females had a higher weight-length ratio, greater than the cube of the length, than that of the immature Buck Lake fish. Pigeon Lake mature males and females had a higher weight-length ratio, less than the cube of the length, than the immature fish but no significant difference occurred between the ratio of the mature male and mature female components of the samples.

The regression equations for the conversion of total length to fork length and fork length to total length of partitioned size class ranges of lake whitefish are presented in Table IV. Samples from both

TABLE I. Comparisons of mean fork lengths (mm) of four ages of Pigeon and Buck Lake lake whitefish. Highly significantly$_{.01}$ greater (>>), significantly$_{.05}$ greater (>) and non-significant (≃) comparisons of means are indicated. The sample size is bracketed.

Lake	Number of Annuli			
	III	IV	V	VI
Pigeon Lake (Miller, 1956)	345.9 (47)	372.9 (145)	391.4 (338)	415.5 (127)
	$\underset{\vee}{\vee}$	$\underset{\vee}{\vee}$	$\underset{\vee}{\vee}$	$\underset{\vee}{\vee}$
Pigeon Lake (1970)	313.2 (30)	348.6 (30)	358.1 (30)	367.8 (30)
	$\overset{\wedge}{\wedge}$	$\overset{\wedge}{\wedge}$	$\overset{\wedge}{\wedge}$	$\overset{\wedge}{\wedge}$
Buck Lake (1970)	388.4 (30)	450.5 (30)	478.5 (30)	475.5 (30)

TABLE II. Comparison of mean fork lengths (mm) of six age classes of lake whitefish from Pigeon and Buck Lake sampled in mid-September of two consecutive years. Highly significant$_{.01}$ greater (>>), significantly$_{.05}$ greater (>) and non-significant (≃) comparisons of means are indicated. Each mean was calculated from thirty observations.

Lake/Year	Number of Annuli					
	I	II	III	IV	V	VI
Pigeon Lake/70	189.73	<< 248.80	<< 313.20	<< 348.60	< 358.07	< 367.77
	∨∨	≃	∧	≃	∧∧	∧∧
Pigeon Lake/71	183.40	<< 244.70	<< 328.27	<< 357.27	<< 373.17	≃ 379.00
	∧∧	∧∧	∧∧	∧∧	∧∧	∧∧
Buck Lake/70	213.57	<< 345.00	<< 388.43	<< 450.53	<< 478.50	≃ 475.57
	∧∧	∨∨	≃	≃	≃	∧∧
Buck Lake/71	232.67	<< 313.20	<< 385.07	<< 441.40	<< 483.03	<< 502.30

TABLE III. Weight of lake whitefish as a function of the length of immature, mature male and mature female components of samples from Pigeon and Buck Lake. The sample size of each partitioned group is presented in brackets. Comparisons of means found highly significantly$_{.01}$ greater (>>) and non-significantly$_{.05}$ different (≃) are indicated.

LAKE	IMMATURE		MATURE MALES		MATURE FEMALES
Pigeon	2.3583	<<	(2.8529	≃	2.8636)
	(80)		(41)		(71)
	$\wedge\wedge$		$\wedge\wedge$		$\wedge\wedge$
Buck	(2.5358	<<	3.1408)	<<	3.1772
	(80)		(80)		(75)

TABLE IV. Equations for the conversion of fork length to total length and total length to fork length of seven size class ranges of lake whitefish. The sample size (N) of each size class range is indicated.

FORK LENGTH SIZE RANGE (mm)	N	EQUATION $\log \hat{Y}_{TL} = \log \bar{y} + b(\log X - \log \bar{x})$
76 - 150	289	= 2.0919 + 1.0059(log X - 2.0420)
151 - 225	76	= 2.3398 + 1.0219(log X - 2.2845)
226 - 300	126	= 2.4512 + 1.0051(log X - 2.3977)
301 - 375	237	= 2.5853 + 0.9720(log X - 2.5337)
376 - 450	161	= 2.6564 + 0.9478(log X - 2.6086)
451 - 525	112	= 2.7292 + 0.9814(log X - 2.6852)
526 - 600	5	= 2.7818 + 0.9332(log X - 2.7410)

TOTAL LENGTH SIZE RANGE (mm)	N	EQUATION $\log \hat{Y}_{FL} = \log \bar{y} + b(\log X - \log \bar{x})$
101 - 175	257	= 2.0567 + 0.9950(log X - 2.1044)
176 - 250	62	= 2.2721 + 0.7625(log X - 2.3256)
251 - 325	120	= 2.3824 + 1.0814(log X - 2.4349)
326 - 400	169	= 2.5121 + 0.9797(log X - 2.5636)
401 - 475	195	= 2.5779 + 1.0385(log X - 2.6277)
476 - 550	129	= 2.6600 + 1.0097(log X - 2.7051)
551 - 625	45	= 2.7104 + 1.0918(log X - 2.7538)

Pigeon and Buck lakes were combined in a given size class for the calculations of the conversion equations.

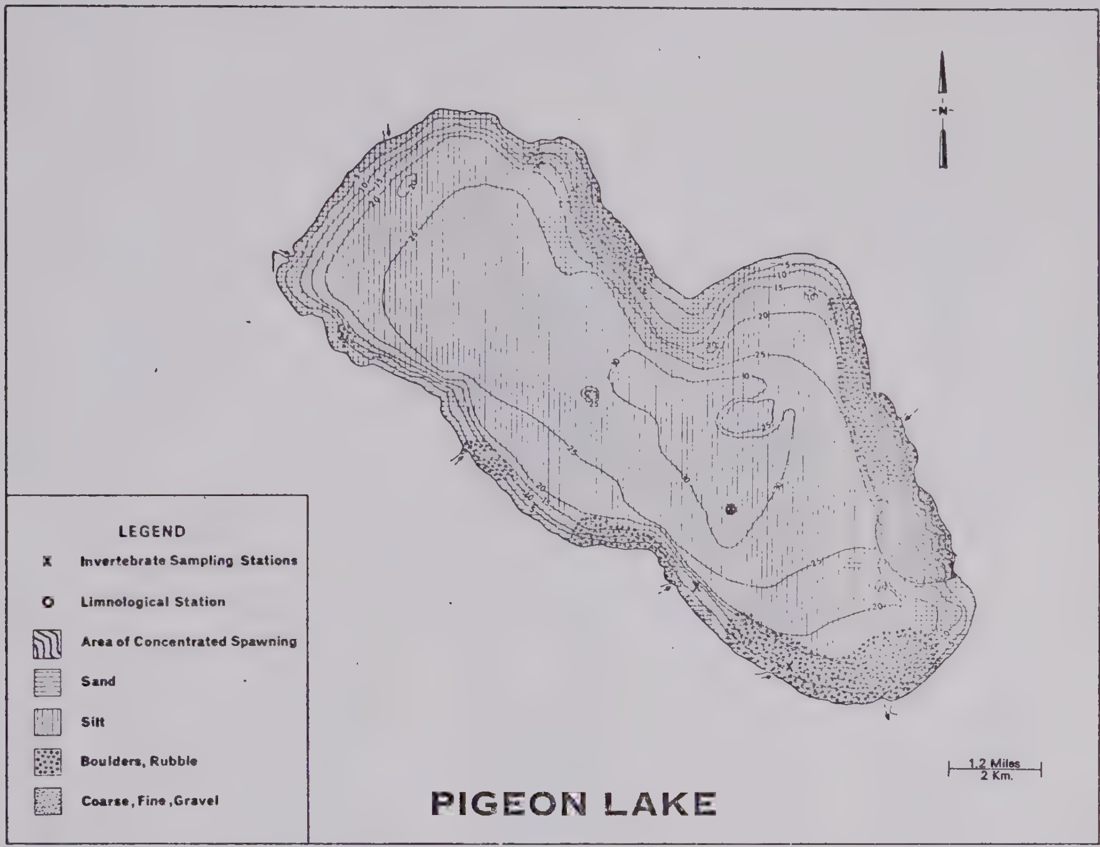
b. Spawning

Restricted areas for spawning in Buck Lake and adequate areas for spawning in Pigeon Lake could increase yearly recruitment, increase intraspecific competition and cause a reduction in the growth of lake whitefish in Pigeon Lake. Both the Pigeon and Buck Lake spawning lake whitefish population concentrated on a boulder, rubble and sand substrate to spawn (Figure 6). This substrate occupied about 16.6 percent of the bottom in Pigeon Lake and 15.4 percent of the bottom in Buck Lake. Lake whitefish were observed spawning in Pigeon Lake in water of two feet in depth over a surficial lake sediment of sand and silt. Areas suitable for lake whitefish spawning are comparable between Pigeon and Buck Lake.

Pigeon Lake lake whitefish could be maturing at an earlier age than the Buck Lake population. A larger spawning population in Pigeon Lake could increase recruitment, increase intraspecific competition and reduce growth rates. Pigeon and Buck Lake lake whitefish are spawning for the first time at the same age (Figure 7). No fish from either lake with two completed annuli was found mature. Some individuals from both lakes with three completed annuli matured and spawned whereas the majority of the sample of age four fish in both lakes matured and spawned. All fish in the samples from both lakes with five completed annuli were mature.

High winds in the fall could increase egg mortality and reduce recruitment (Miller, 1952). If the Buck Lake population spawns earlier than the Pigeon Lake population, the Buck Lake eggs could have increased

FIGURE 6. Location of concentrated lake whitefish spawning in Pigeon and Buck Lakes. The location of the bottom sampling stations in the three surficial lake sediments and the plankton and limnological stations are designated.


LEGEND
X Invertebrate Sampling Stations
O Limnological Station
Area of Concentrated Spawning
Sand
Silt
Boulders, Rubble
Coarse, Fine, Gravel
-N-
1.2 Miles
2 Km.
PIGEON LAKE

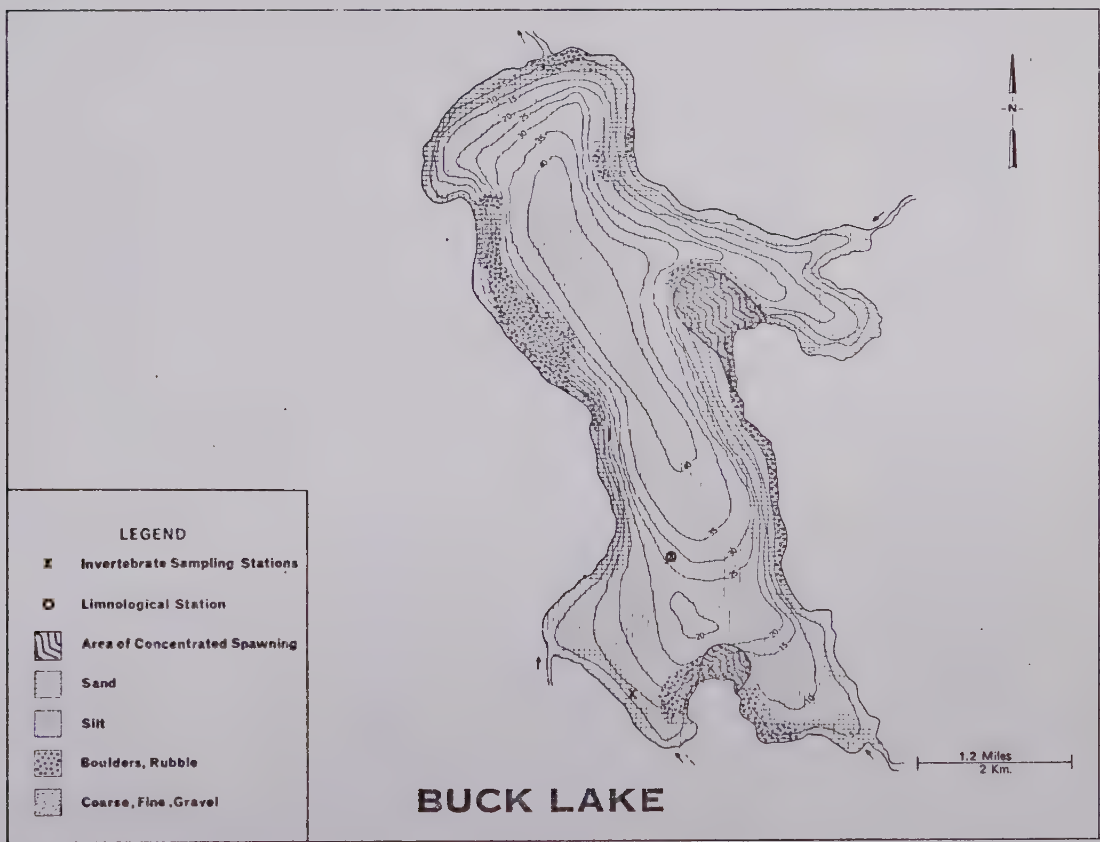

LEGEND
X Invertebrate Sampling Stations
O Limnological Station
Area of Concentrated Spawning
Sand
Silt
Boulders, Rubble
Coarse, Fine, Gravel
-N-
1.2 Miles
2 Km.
BUCK LAKE

Figure 6

FIGURE 7. Per cent mature lake whitefish in samples with from two to five completed annuli from Pigeon and Buck Lake. The sample size for each sex in each age class is presented.

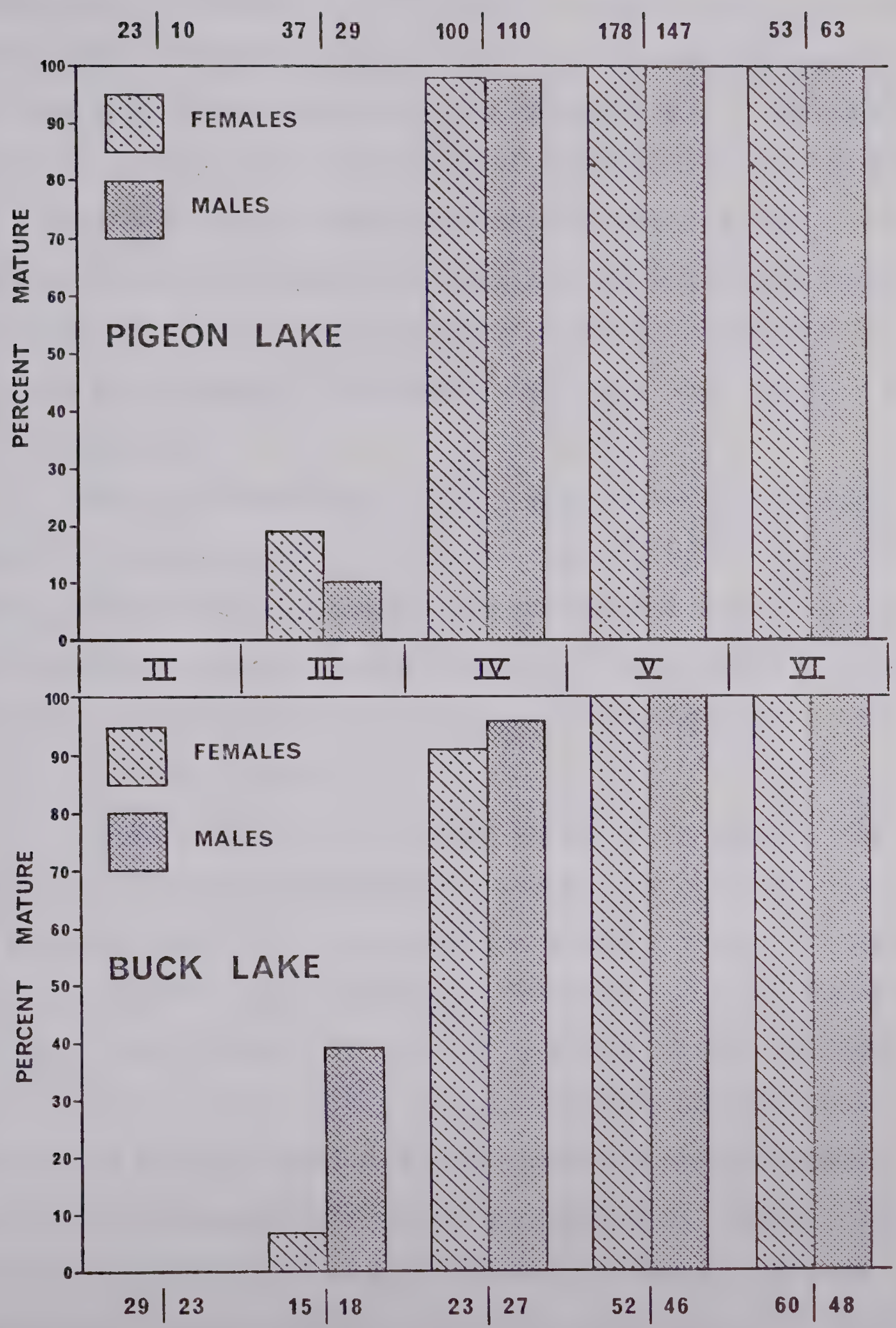

23 | 10
37 | 29
100 | 110
178 | 147
53 | 63
FEMALES
MALES
PIGEON LAKE
PERCENT MATURE
100
90
80
70
60
50
40
30
20
10
0
II
III
IV
V
VI
FEMALES
MALES
BUCK LAKE
PERCENT MATURE
29 | 23
15 | 18
23 | 27
52 | 46
60 | 48

Figure 7

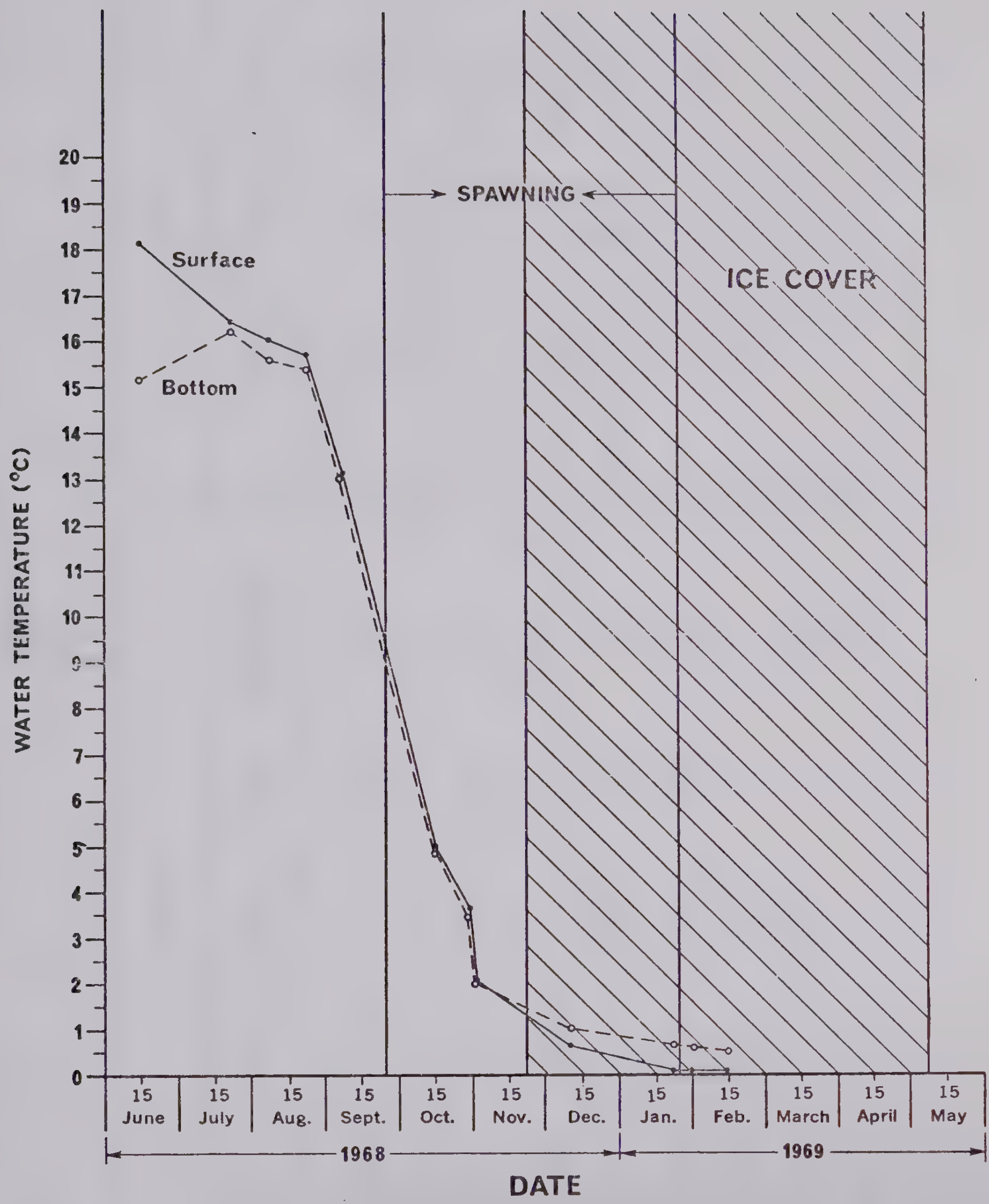
mortality that would reduce intraspecific competition and increase growth rates of the survivors. An extensive spawning period over a wide range of water temperatures occurred in Pigeon Lake (Figure 8). Ripe fish were found on the spawning beds in the latter part of September to the latter part of January when the water temperature varied from 9.2 to 1°C. Spawning occurred in both open water and under ice cover. Active spawning occurred at night but fish were observed on the spawning beds during the day. Ripe females were captured on the spawning beds in Buck Lake from September 28 to December 30 in open water and under ice cover respectively.

The peak spawning periods of lake whitefish in Pigeon Lake occurred in the open water and under ice cover (Table V). The ratio of female to male fish in the samples from the spawning beds varied throughout the sampling period. Overnight sets of gill nets masked the detection of differential movements of the sexes on the spawning beds.

c. Egg Incubation

Genetic control of the incubation period of eggs from the Pigeon Lake lake whitefish population could be different than that of the Buck Lake population. Larger eggs could have a shorter incubation period than smaller eggs. A prolonged incubation period for Pigeon Lake eggs could favour survival of hatching y-o-y fish. Pigeon Lake eggs could be hatching in the spring coincident with the plankton pulse whereas Buck Lake eggs could be hatching under the ice with higher mortality of progeny due to a lack of available food. The incubation period of the Pigeon and Buck Lake eggs to the eyed egg stage, the occurrence of the first hatched fish and the occurrence of the first modal hatch were similar (Table VI). Incubating water temperature

FIGURE 8. Surface and bottom water temperatures and the period of spawning and ice cover on the Pigeon Lake lake whitefish spawning beds.



SPAWNING
ICE COVER
Surface
Bottom
WATER TEMPERATURE (°C)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
15 June
15 July
15 Aug.
15 Sept.
15 Oct.
15 Nov.
15 Dec.
15 Jan.
15 Feb.
15 March
15 April
15 May
1968
1969
DATE

Figure 8

TABLE V. Number (N) of each sex of adult lake whitefish captured on the spawning beds in Pigeon Lake over a four month period. The number of fish in each of four states of maturity is presented. Percentages appear in brackets.

Date	Sample	Females					Males				
1968	Size	N	Ripe	Spent	Mature	Maturing	N	Ripe	Spent	Mature	Maturing
Sept. 26	113	46 (40.7)	1 (2.2)	0	45 (97.8)	0	67 (59.3)	0	0	67 (100)	0
Oct. 15	120	20 (16.7)	20 (100)	0	0	0	100 (83.3)	97 (97.0)	3 (3.0)	0	0
Oct. 17	37	20 (54.1)	0	0	20 (100)	0	17 (45.9)	0	0	17 (100)	0
Oct. 18	33	12 (36.4)	3 (25.0)	0	9 (75.0)	0	21 (63.6)	12 (57.1)	0	9 (42.9)	0
Oct. 31	113	43 (38.1)	15 (34.9)	25 (58.1)	3 (7.0)	0	68 (61.9)	28 (41.2)	28 (41.2)	9 (13.2)	3 (4.4)
Nov. 5	85	35 (41.2)	6 (17.1)	28 (80.0)	1 (2.9)	0	50 (58.8)	0	45 (90.0)	2 (4.0)	3 (6.0)
Dec. 11	89	67 (75.3)	25 (37.3)	42 (62.7)	0	0	22 (24.7)	1 (4.5)	19 (86.4)	0	2 (9.1)
Jan. 24	73	54 (73.9)	13 (24.1)	12 (22.2)	0	29 (53.7)	19 (26.1)	0	3 (15.8)	0	16 (84.2)
Feb. 14	72	41 (56.9)	1 (2.4)	0	0	40 (97.6)	31 (43.1)	0	0	0	31 (100)

TABLE VI. Incubation period for lake whitefish eggs from Pigeon and Buck Lakes to the occurrence of eyed eggs, first hatch of fish and first occurrence of modal hatching (>400 fish) when incubated under three different temperature regimes.

Sample	Incubation Regime		Accumulated Days from Fertilization		
	Days	Temp. (^{o}C)	Eyed	First Hatch	Modal Hatch
Pigeon Lake	D*	4	30	107	156
Buck Lake	D	4	32	83	144
Pigeon Lake	18	2	48		
	7	2.5			
	7	3.0			
	7	3.5			
	D	4.0		107	162
Buck Lake	21	2	52		
	7	2.5			
	7	3.0			
	7	3.5			
	D	4.0		107	161
Pigeon Lake	D	2.0	48	132	191
Buck Lake	D	2.0	51	125	193

* Duration of experiment

controlled the development rates of both lots of eggs and genetic differences were obscure.

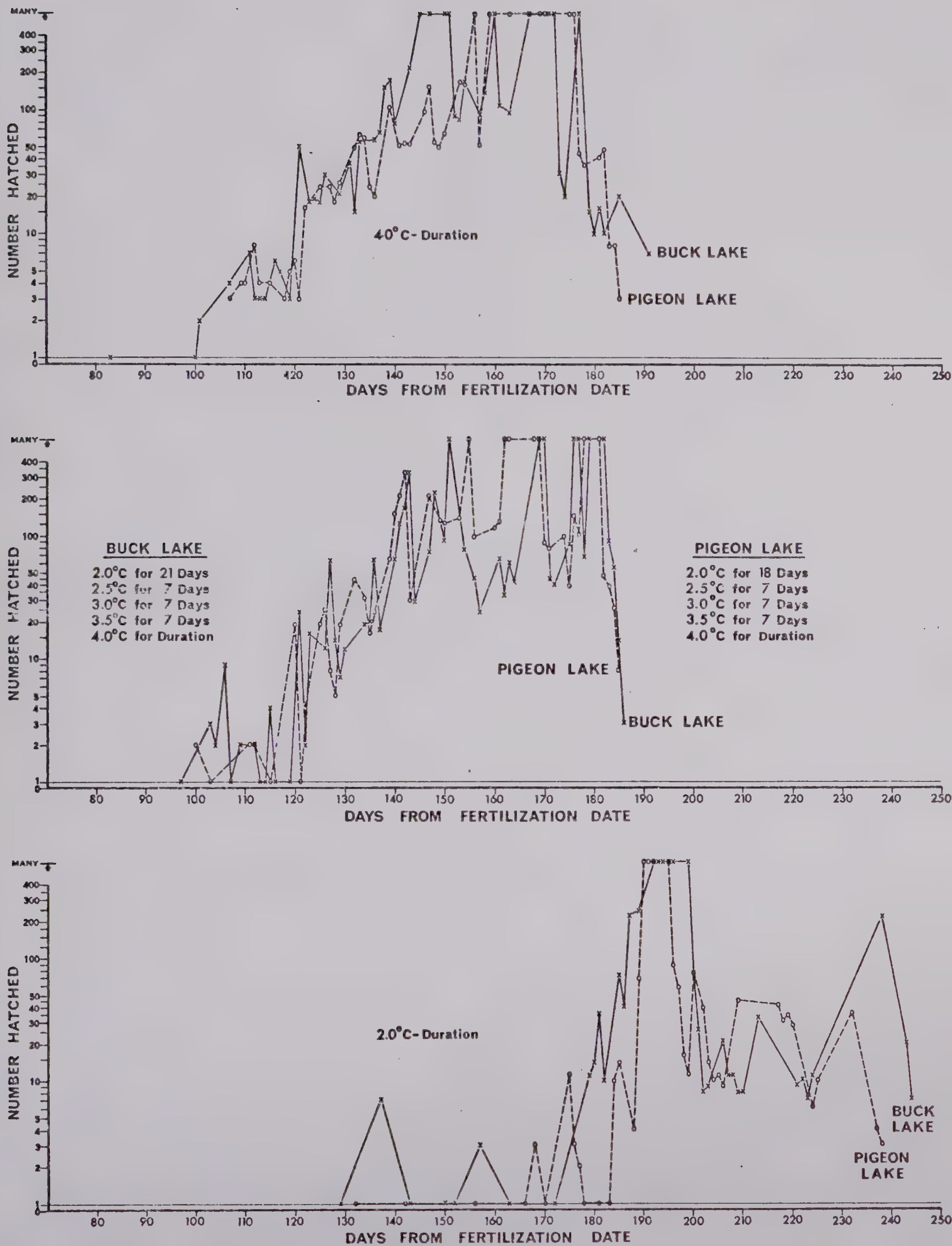
The period of hatching of Pigeon and Buck Lake lake whitefish eggs, incubated in 1970/71 under different temperature regimes, was similar (Figure 9). Eggs incubated at 2°C to the eyed egg stage and raised to and incubated at 4°C does not appear to alter the incubation period from that of eggs incubated at a constant temperature of 4°C. Incubation of both Pigeon Lake and Buck Lake eggs at a constant temperature of 2°C prolonged the first occurrence of a modal hatch by forty days. Eggs incubated at 4°C hatch over a period of ninety days while eggs incubated at 2°C hatched over a period of 115 days. Lower incubation temperatures prolong the incubation period and extend the range of time that hatching occurs.

The incubation water temperature regime controls the incubation period of lake whitefish eggs (Figure 10). In 1971/72, eggs incubated at 2.0°C until January then incubated at 4.0°C for the duration of the experiment all hatched prior to spring breakup on both lakes. Eggs incubated continuously at 2.0°C had a modal hatch that occurred well after the ice left both lakes. Eggs incubated at 2.0 to 4.0°C had a reduced hatching period over those incubated continuously at 2.0°C. Temperature readings on the bottom under ice cover on the Buck Lake spawning beds revealed that the actual egg incubation water temperature approached 1.0°C.

d. Gonad Maturation

The mature Pigeon Lake lake whitefish population has similar ratios of gonad weight to body weight to that of the Buck Lake population (Figure 11). The slopes of the two regression lines do not

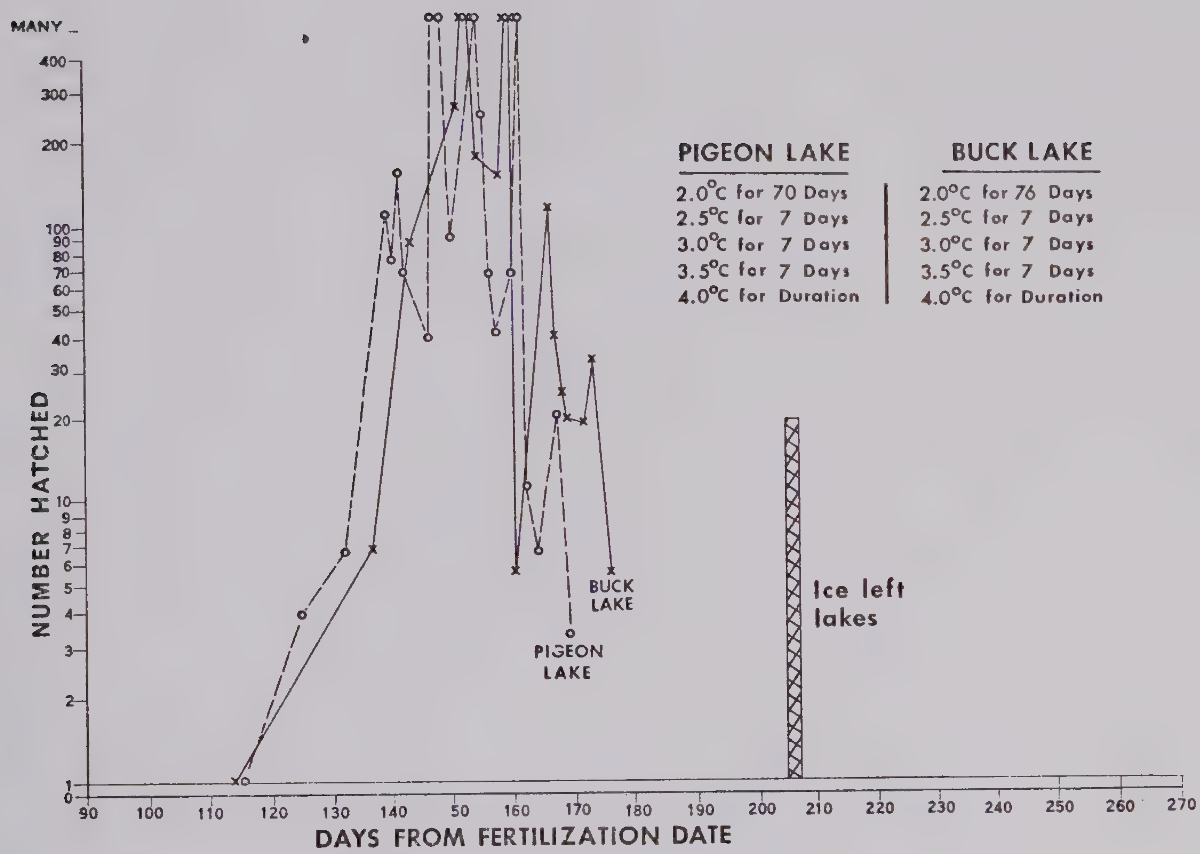
FIGURE 9. Number of fish hatching from Pigeon and Buck Lake eggs incubated under three different temperature regimes. The incubation temperature regimes are presented for each experiment.



MANY
NUMBER HATCHED
4.0°C - Duration
BUCK LAKE
PIGEON LAKE
DAYS FROM FERTILIZATION DATE
BUCK LAKE
2.0°C for 21 Days
2.5°C for 7 Days
3.0°C for 7 Days
3.5°C for 7 Days
4.0°C for Duration
PIGEON LAKE
2.0°C for 18 Days
2.5°C for 7 Days
3.0°C for 7 Days
3.5°C for 7 Days
4.0°C for Duration
PIGEON LAKE
BUCK LAKE
DAYS FROM FERTILIZATION DATE
2.0°C - Duration
BUCK LAKE
PIGEON LAKE
DAYS FROM FERTILIZATION DATE

Figure 9

FIGURE 10. Number of fish hatching from Pigeon and Buck Lake lake whitefish eggs incubated under two different temperature regimes. The incubation water temperature regimes are presented. The period of hatching relative to the date when the ice left the lakes is indicated.


MANY
NUMBER HATCHED
PIGEON LAKE
2.0°C for 70 Days
2.5°C for 7 Days
3.0°C for 7 Days
3.5°C for 7 Days
4.0°C for Duration
BUCK LAKE
2.0°C for 76 Days
2.5°C for 7 Days
3.0°C for 7 Days
3.5°C for 7 Days
4.0°C for Duration
BUCK LAKE
PIGEON LAKE
Ice left lakes
DAYS FROM FERTILIZATION DATE

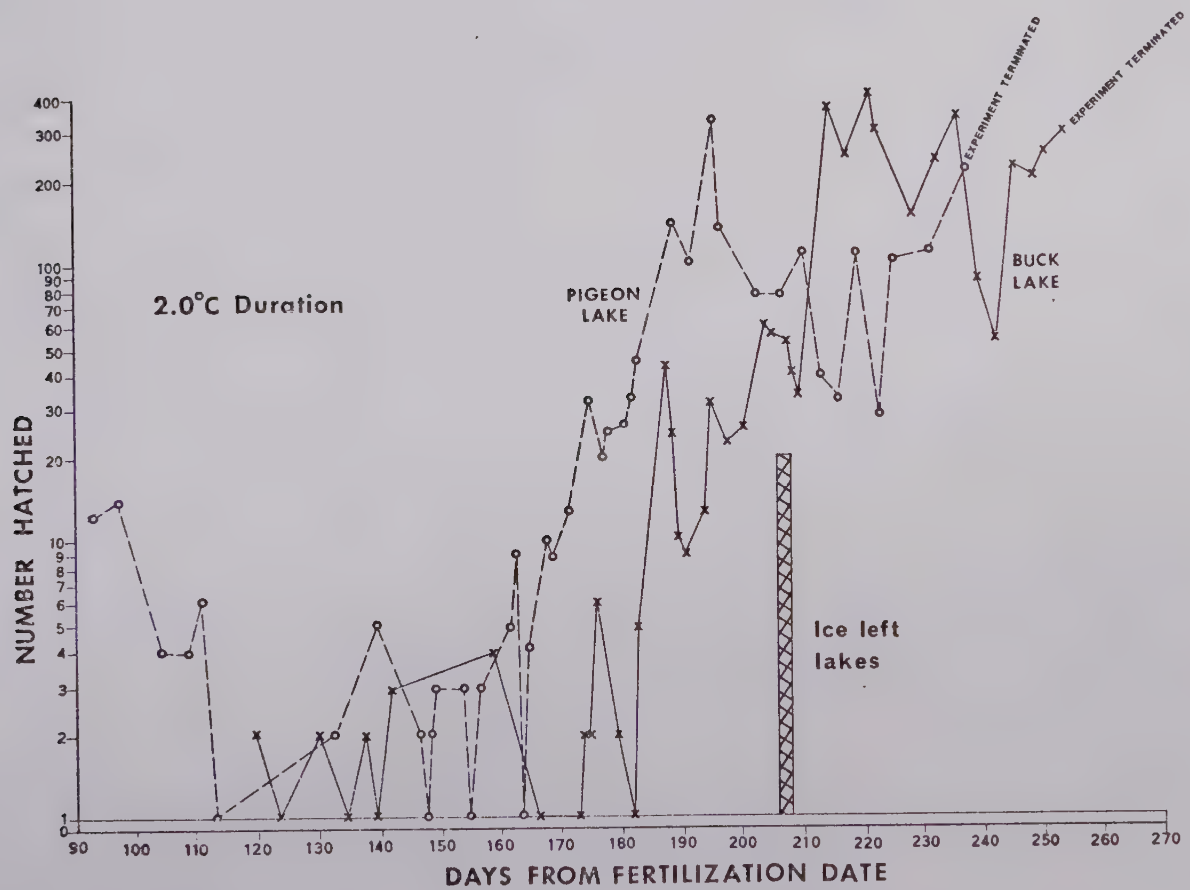

EXPERIMENT TERMINATED
EXPERIMENT TERMINATED
NUMBER HATCHED
2.0°C Duration
PIGEON LAKE
BUCK LAKE
Ice left lakes
DAYS FROM FERTILIZATION DATE

Figure 10

FIGURE 11. Regression of the mean ratio (N=30) of gonad weight to body weight of female lake whitefish from Pigeon Lake (PL) and Buck Lake (BL). The base date is April 1, 1970. The regression equation for each line is presented.

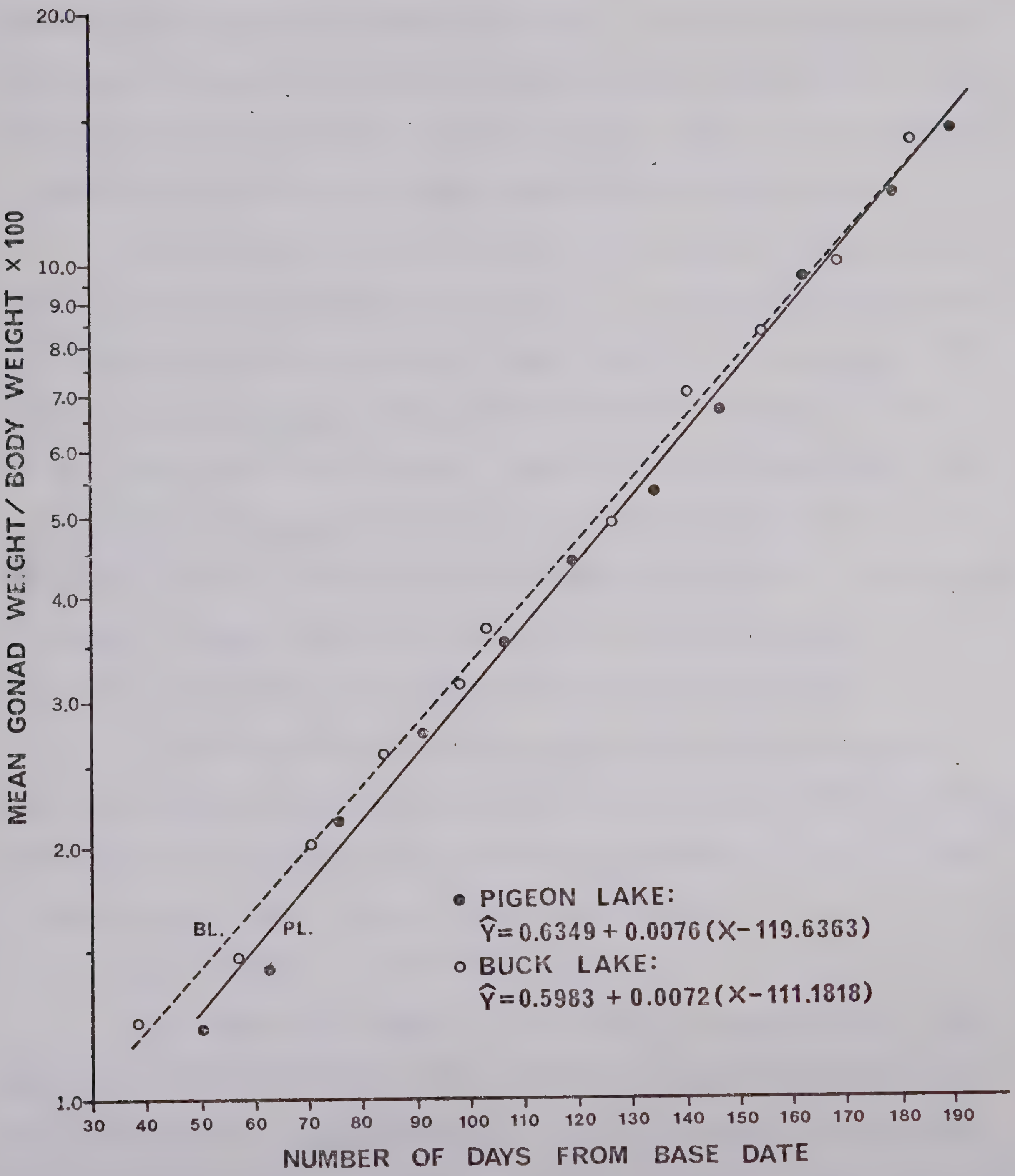

20.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
MEAN GONAD WEIGHT/ BODY WEIGHT × 100
30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190
NUMBER OF DAYS FROM BASE DATE
BL.
PL.
PIGEON LAKE:
$\hat{Y}=0.6349+0.0076(X-119.6363)$
BUCK LAKE:
$\hat{Y}=0.5983+0.0072(X-111.1818)$

Figure 11

differ statistically and are both estimates of the same line (P>0.05). Female fish collected from both lakes, sampled and compared from January to March had no appreciable increase in the ratio of gonad weight to body weight throughout the sampling period. In May, after the ice left the lakes, the gonad ratio data increased significantly every two weeks. Increase in water temperature (Figure 4) as the lake warms in the spring is positively correlated with gonad development and maturation.

The fecundity of the Pigeon Lake lake whitefish is lower than that of the Buck Lake population (Figure 12). The Buck Lake population has a highly significantly greater slope (4.03) of the regression line than the Pigeon Lake population (1.04) (P<0.0001). Pigeon Lake fish produce fewer eggs per unit weight than the Buck Lake population. The deviations from the regression line of the fecundity of individual Buck Lake fish (r=0.60) is much greater than that of Pigeon Lake fish (r=0.66). The number of eggs produced by slow growing individuals appears to be more closely controlled than that of faster growing individuals.

Each female lake whitefish in Buck Lake produces about four times the number of eggs as each Pigeon Lake female lake whitefish (Table VII). Buck Lake females produce about one and one-half times the number of eggs per unit body weight as Pigeon Lake females.

e. Morphometric and Meristic Data

The number and length of gill rakers in a population of lake whitefish could be altered through selection. The feeding habits of or food available to a population could select individuals that are better adapted to utilize the available food (Kliewer, 1970). Pigeon Lake lake whitefish could be plankton feeding whereas the Buck Lake population could be bottom feeding. Different feeding habits of these

FIGURE 12. Fecundity of a sample of sixty female lake whitefish from Pigeon Lake and sixty from Buck Lake.

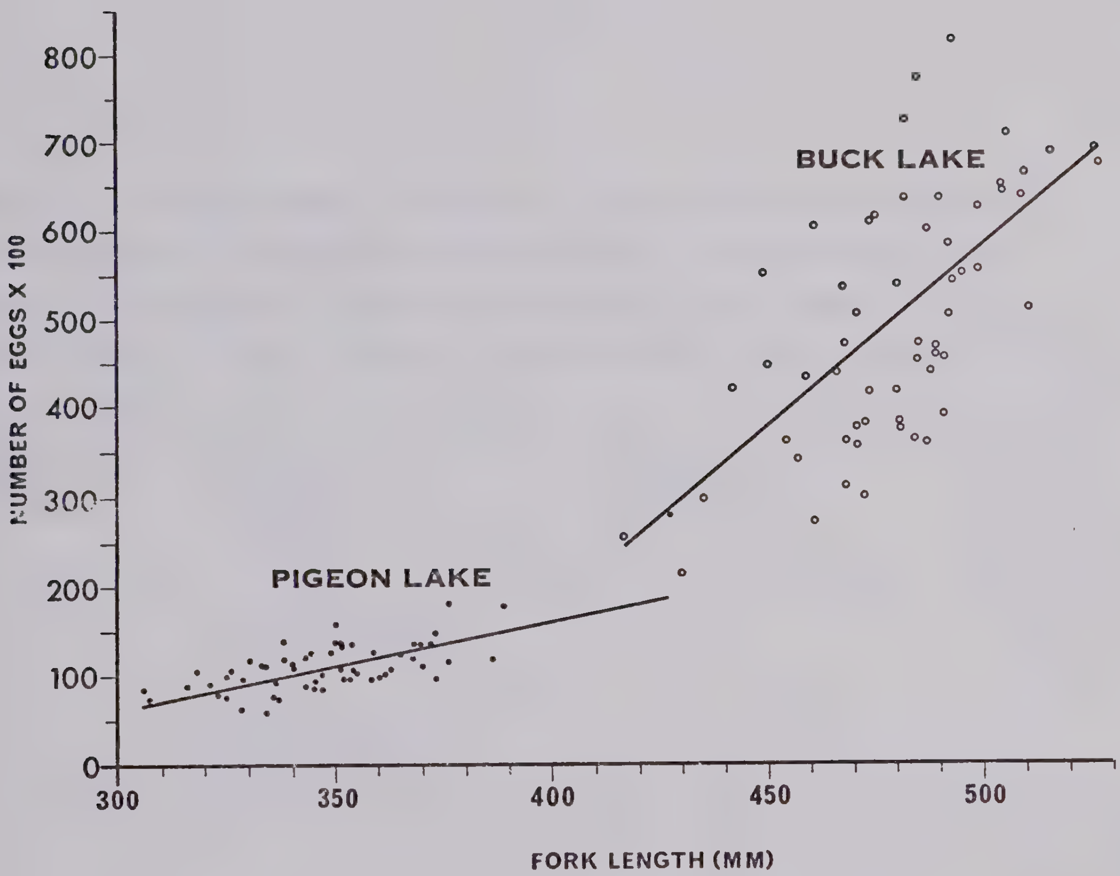

BUCK LAKE
PIGEON LAKE
NUMBER OF EGGS X 100
0
100
200
300
400
500
600
700
800
300
350
400
450
500
FORK LENGTH (MM)

Figure 12

TABLE VII. Average number of eggs per kilogram body weight and the range (brackets) of a sample of sixty female lake whitefish from Pigeon and Buck Lakes. The average weight of each sample and the average number of eggs produced by each female in each lake is presented.

LAKE	AVERAGE NO. EGGS/kgm.	AVERAGE WT. SAMPLE(gm.)	AVERAGE NO. EGGS/FISH
Pigeon	18,010 (10,940-24,290)	617	11,112
Buck	27,670 (16,380-39,030)	1775	49,114

two populations could be reflected in the length and number of gill rakers of each population. Pigeon Lake lake whitefish did not differ significantly in the number of gill rakers on the first arch from that of the Buck Lake sample but had a higher significant ratio of gill raker length to total length than the Buck Lake sample (Table VIII). The mean total length of the Pigeon Lake sample was highly significantly lower than the Buck Lake sample. Detailed statistical computation for these data are presented in Appendix I.

f. Divergence in Growth

Larger fish tend to produce larger eggs and larger young-of-the-year (Gerking, 1967). Buck Lake whitefish are larger than Pigeon Lake fish and could produce larger eggs and larger young-of-the-year. Buck Lake fish could have an initial advantage for increased growth over that of the Pigeon Lake population. However, the smaller Pigeon Lake female fish produced larger eggs than the larger female Buck Lake fish (Table IX). The mean oviduct egg size in the Pigeon Lake fish in the 1969 samples was similar to that of the 1970 samples but both samples had larger eggs than that of the 1970 Buck Lake sample. No difference was detected between the location of the gonad sampled in both lake whitefish populations. All eggs in the gonad mature at the same rate and ripen at the same time. Detailed statistical computations for these data are presented in Appendix J.

Eggs experimentally reared in the laboratory were larger in the Pigeon Lake population than the Buck Lake population (Table X). Eyed eggs did not differ in size from hardened eggs of both populations. No differences were found in the size of the eggs when hardened and incubated in either Pigeon Lake or Buck Lake water. Detailed statistical

TABLE VIII. Mean gill raker number and ratio of gill raker length to total length X 100 of a sample of fifty fish from each of Pigeon and Buck Lakes. Highly significantly$_{.01}$ greater (>>) and non-significantly$_{.05}$ (≃) different comparison of means are indicated. The mean ($\bar{x}$) total length (mm) of each sample is indicated.

Data	Pigeon Lake $\bar{x}$ = 399.7		Buck Lake $\bar{x}$ = 504.0
Gill Raker Number	27.08	≃	27.36
Gill Raker X 100/Total Length	1.8232	>>	1.6770

TABLE IX. Mean oviduct egg size (mm) of thirty female lake whitefish sampled in two successive years in Pigeon Lake, one year in Buck Lake. The means of samples from three gonad locations are presented. Non-significant$_{.05}$ (≃) and highly significantly$_{.01}$ greater (>>) comparisons of means are indicated.

Pigeon Lake							Buck Lake		
1969				1970			1970		
Ant.	Mid.	Post.		Ant.	Mid.	Post.	Ant.	Mid.	Post.
(1.8500≃	1.8566≃	1.8623)	≃	(1.8713≃	1.8840≃	1.8726) >>	(1.7726≃	1.7580≃	1.7733)

TABLE X. Mean egg size (mm) of Pigeon and Buck Lake eggs fertilized, hardened and incubated in Pigeon and Buck Lake water and measured at two different stages in development. Highly significantly$_{.01}$ greater (>>) and non-significant$_{.05}$ (≃) comparisons of means are indicated.

	Pigeon Lake Eggs				Buck Lake Eggs		
	Pigeon Lake Water		Buck Lake Water		Pigeon Lake Water		Buck Lake Water
Hardened	{(2.72	≃	2.67)}	>>	{(2.44	≃	2.45)}
		≃				≃	
Eyed	{(2.75	≃	2.63)}	>>	{(2.44	≃	2.46)}

computations for these data are presented in Appendix K.

The size of young-of-the-year fish emerging from larger Pigeon Lake eggs was similar to that of y-o-y emerging from smaller Buck Lake eggs (Table XI). Eggs from Pigeon and Buck Lake fish incubated in tray cultures under the higher temperature regime (2^{o} to $4^{o}C$) that hatched earlier (153 to 167 days) produced, on the average, smaller fish than those incubated under a lower temperature regime ($2.0^{o}C$) and having a prolonged incubation period (183 to 231 days). The larger Pigeon Lake eggs incubated for the longest time (167 days) under the higher temperature regime (2^{o} to $4.0^{o}C$) produced larger y-o-y fish but both Pigeon and Buck Lake eggs produced similar sized fish when incubated for 231 to 216 days under the lower temperature regime ($2^{o}C$). In the $2^{o}C$ experiment, the temperature approaching that of the lake incubation water temperature ($1^{o}C$), the period of incubation to hatching affected the size of the emerging y-o-y. The longer incubation period produced the larger y-o-y. The size of the eggs did not affect the size of the emerging y-o-y. An unaccountable variation in the size of the y-o-y was obtained from eggs incubated in the jar cultures. The incubation period and thus the size of the emerging y-o-y was affected by both the incubating water temperature and the degree of aggitation of the eggs in the individual jars.

Pigeon and Buck Lake y-o-y fish reared under similar conditions did not differ in growth rates (Table XII). Genetic control of the growth rates of the two populations in the early stages of growth appear similar. Detailed statistical computations of these data are presented in Appendix L.

Divergence in growth of Pigeon and Buck Lake lake whitefish occurs during the winter months of their first year of life (Table XIII).

TABLE XI. Mean total length (mm) of Pigeon Lake (PL) and Buck Lake (BL) lake whitefish emerging from eggs incubated under two different temperature regimes. The days of incubation to hatching are subscript to the symbols for each lake. Any two means not underlined by the same line are significantly$_{.05}$ different. Each mean was calculated from the measurements of thirty fish.

TEMPERATURE REGIME	LAKE - INCUBATION DAYS									
2^{o} to 4^{o}C	PL_{167}	BL_{167}	BL_{153}	PL_{153}						
	11.45	11.07	11.00	10.97						
2^{o}C	BL_{231}	PL_{231}	BL_{216}	PL_{216}	PL_{174}	PL_{202}	BL_{202}	BL_{174}	PL_{183}	BL_{183}
	11.84	11.74	11.65	11.50	11.48	11.46	11.19	11.12	11.10	11.03

TABLE XII. Mean total length (mm) of samples of lake whitefish from Pigeon and Buck Lakes incubated from eggs and reared under the same conditions and measured at two periods from the hatching date. Non-significant$_{.05}$ (≃) comparisons of means are indicated.

Rearing Period (Days)	Pigeon Lake		Buck Lake
57	31.53	≃	31.33
	≃		≃
60 to 63	31.50	≃	32.00

TABLE XIII. Mean fork length (mm) and sample size in brackets of trawl caught (T) and monofilament caught (M) samples of young-of-the-year and yearling lake whitefish from Pigeon and Buck Lakes. Highly significant$_{.01}$ (>>) and non-significant$_{.05}$ (≃) comparisons of means are indicated.

SAMPLING GEAR	AGE	PIGEON LAKE DATE	PIGEON LAKE MEAN		BUCK LAKE MEAN	BUCK LAKE DATE
T	0+	19/08/71	89.61 (36)	≃	91.15 (41)	18/08/71
				^^		
T	0+	8/09/71	103.00 (7)	≃	102.70 (71)	1/09/71
				^^		
M	0+	17/12/71	119.46 (48)	?	129.00 (3)	30/12/71
			^^		^^	
M	1+	6/06/72	131.80 (44)	<<	143.03 (38)	31/05/72

Young-of-the-year fish from both lakes increased in size during both the summer and winter months. The growth rate of y-o-y fish in Pigeon Lake paralleled that of Buck Lake during the summer months but a difference in the growth rates occurred during the winter with the Pigeon Lake fish having a slower growth rate. The small sample size (3) from Buck Lake in December masks detection of statistical difference between the size of the fish. Both 1 (2.54 cm) and 1½ (3.81 cm) inch stretched mesh monofilament gill nets were set in both lakes. In May, 1972, all yearling samples were captured in one inch (2.54 cm) mesh in Pigeon Lake and 1½ (3.81 cm) inch mesh in Buck Lake. Over nine times the fishing effort in Buck Lake than that of Pigeon Lake captured 39 and 48 y-o-y respectively. Detailed statistical computations for these data are presented in Appendix M.

The divergence in growth between Pigeon and Buck Lake lake whitefish populations is graphically illustrated in figure 13. Although the Pigeon Lake population produces larger eggs individuals from both populations were of similar size at hatching and were of similar size when reared under controlled temperature, light and food supply. The growth of y-o-y fish sampled in both lakes was similar until September but divergence was documented as occurring before the following spring.

g. Species Present and Abundance

Nine species of fish were captured in Pigeon Lake and ten species were captured in Buck Lake during the course of these studies (Table XIV). Walleye and brook stickleback were present in the Buck Lake samples but absent in the samples from Pigeon Lake. Emerald shiners were found in the Pigeon Lake samples but were absent from the samples collected in Buck Lake.

The commercial harvest of lake whitefish from Buck Lake has on the average been higher per unit area than that of Pigeon Lake (Table XV). Since 1942, Pigeon Lake has produced and average harvest of 10.8

FIGURE 13. Graphic presentation of the size of Pigeon and Buck Lake lake whitefish oviduct, hardened and eyed eggs and hatching, experimentally reared and lake samples of young-of-the-year fish. A vertical separation of plotted points indicates the mean size is highly significantly$_{.01}$ different.

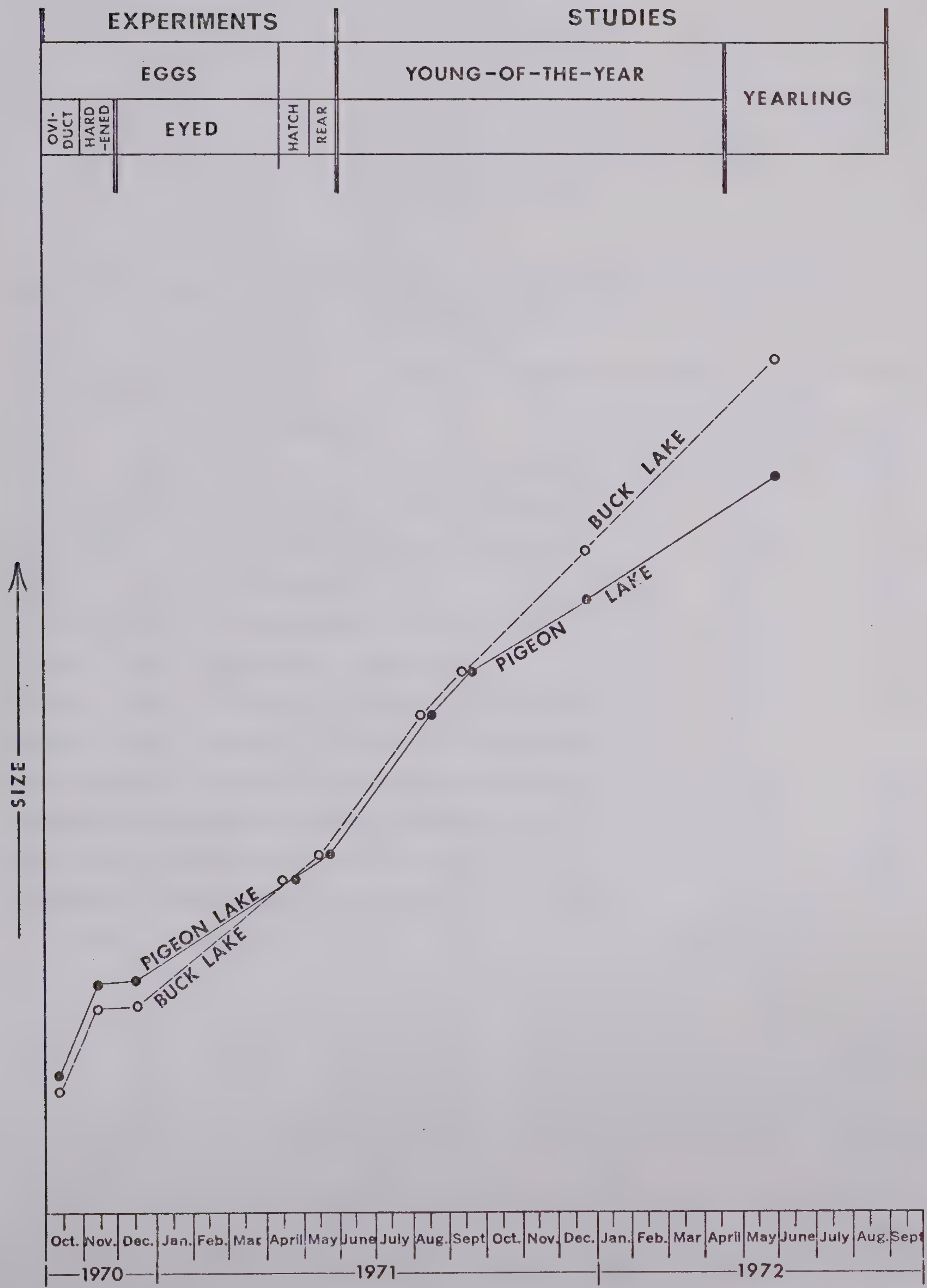

EXPERIMENTS
STUDIES
EGGS
YOUNG-OF-THE-YEAR
YEARLING
OVI-DUCT
HARD-ENED
EYED
HATCH
REAR
SIZE
BUCK LAKE
PIGEON LAKE
PIGEON LAKE
BUCK LAKE
Oct.
Nov.
Dec.
Jan.
Feb.
Mar
April
May
June
July
Aug.
Sept
Oct.
Nov.
Dec.
Jan.
Feb.
Mar
April
May
June
July
Aug.
Sept
1970
1971
1972

Figure 13

TABLE XIV. Species of fish observed in Pigeon Lake and Buck Lake in 1968 to 1972

Species	Lake	
	Pigeon	Buck
Lake whitefish, *Coregonus clupeaformis* (Mitchill)	X	X
White sucker, *Catostomus commersoni* (Lacépède)	X	X
Burbot, *Lota lota* (Linnaeus)	X	X
Yellow perch, *Perca flavescens* (Mitchill)	X	X
Northern Pike, *Esox lucius* Linnaeus	X	X
Spottail shiner, *Notropis hudsonius* (Clinton)	X	X
Emerald shiner, *Notropis atherinoides* Rafinesque	X	-
Trout-perch, *Percopsis omiscomaycus* (Walbaum)	X	X
Walleye, *Stizostedion vitreum vitreum* (Mitchill)	-	X
Iowa darter, *Etheostoma exile* (Girard)	X	X
Brook stickleback, *Culaea inconstans* (Kirtland)	-	X

TABLE XV. Annual commercial harvest (lbs.) of lake whitefish from Pigeon Lake and Buck Lake over a twenty-nine year period. The harvest per surface acre and the legal mesh size prescribed for each fishery is presented.

Year	Pigeon Lake			Buck Lake		
	Mesh	Harvest	Harvest/ acre	Mesh	Harvest	Harvest/ acre
42/43	$5\frac{1}{2}$''(13.97cm)	324,985	13.7	$5\frac{1}{2}$''(13.97cm)	54,791	8.9
43/44	$5\frac{1}{2}$''(13.97cm)	444,190	18.7	$5\frac{1}{2}$''(13.97cm)	75,700	12.3
44/45	$5\frac{1}{2}$''(13.97cm)	390,000	16.5	$5\frac{1}{2}$''(13.97cm)	57,618	9.4
45/46	$5\frac{1}{2}$''(13.97cm)	381,470	16.1	$5\frac{1}{2}$''(13.97cm)	57,729	9.4
46/47	$5\frac{1}{2}$''(13.97cm)	160,000	6.7	$5\frac{1}{2}$''(13.97cm)	52,039	8.5
47/48	$5\frac{1}{2}$''(13.97cm)	---*	--	$5\frac{1}{2}$''(13.97cm)	58,268	9.5
48/49	$5\frac{1}{2}$''(13.97cm)	63,800	2.7	$5\frac{1}{2}$''(13.97cm)	60,000	9.8
49/50	$5\frac{1}{2}$''(13.97cm)	---	--	$5\frac{1}{2}$''(13.97cm)	56,775	9.2
50/51	$5\frac{1}{2}$''(13.97cm)	66,000	2.8	$5\frac{1}{2}$''(13.97cm)	65,920	10.7
51/52	$5\frac{1}{2}$''(13.97cm)	187,435	7.9	$5\frac{1}{2}$''(13.97cm)	100,000	16.3
52/53	$5\frac{1}{2}$''(13.97cm)	231,000	9.7	$5\frac{1}{2}$''(13.97cm)	109,000	17.8
53/54	$5\frac{1}{2}$''(13.97cm)	200,000	8.4	$5\frac{1}{2}$''(13.97cm)	78,850	12.8
54/55	$5\frac{1}{2}$''(13.97cm)	336,000	14.2	$5\frac{1}{2}$''(13.97cm)	65,000	10.6
55/56	$5\frac{1}{2}$''(13.97cm)	384,000	16.2	$5\frac{1}{2}$''(13.97cm)	68,200	11.1
56/57	$5\frac{1}{2}$''(13.97cm)	273,528	11.5	$5\frac{1}{2}$''(13.97cm)	53,000	8.6
57/58	$5\frac{1}{2}$''(13.97cm)	243,528	10.3	$5\frac{1}{2}$''(13.97cm)	63,576	10.3
58/59	$5\frac{1}{2}$''(13.97cm)	219,000	9.2	$5\frac{1}{2}$''(13.97cm)	67,783	11.0
59/60	$5\frac{1}{2}$''(13.97cm)	233,446	9.8	$5\frac{1}{2}$''(13.97cm)	118,350	19.3
60/61	$5\frac{1}{2}$''(13.97cm)	338,000	14.3	$5\frac{1}{2}$''(13.97cm)	290,457	47.2
61/62	$5\frac{1}{2}$''(13.97cm)	158,522	6.7	$5\frac{1}{2}$''(13.97cm)	61,936	10.1
62/63	$5\frac{1}{2}$''(13.97cm)	204,000	8.6	$5\frac{1}{2}$''(13.97cm)	62,865	10.2
63/64	$5\frac{1}{2}$''(13.97cm)	204,000	8.6	$5\frac{1}{2}$''(13.97cm)	79,600	12.9
64/65	$5\frac{1}{2}$''(13.97cm)	170,131	7.2	$5\frac{1}{2}$''(13.97cm)	76,000	12.4
65/66	$5\frac{1}{2}$''(13.97cm)	214,314	9.0	$5\frac{1}{2}$''(13.97cm)	47,743	7.8
66/67	$5\frac{1}{2}$''(13.97cm)	169,999	7.2	$5\frac{1}{2}$''(13.97cm)	62,856	10.2
67/68	$4\frac{1}{2}$''(11.43cm)	223,293	9.4	$5\frac{1}{2}$''(13.97cm)	40,404	6.6
68/69	$3\frac{1}{2}$''(8.89cm)	302,488	12.8	$5\frac{1}{2}$''(13.97cm)	49,036	8.0
69/70	$3\frac{1}{2}$''(8.89cm)	455,136	19.2	$5\frac{1}{2}$''(13.97cm)	62,320	10.1
70/71	$3\frac{1}{2}$''(8.89cm)	341,463	14.4	$5\frac{1}{2}$''(13.97cm)	59,422	9.7

* No commercial fishery.

pounds per surface acre whereas Buck Lake has produced an average of 12.1 pounds per unit area. The legal mesh size for the Pigeon Lake commercial fishery was reduced in the 1967/68 winter fishery and again in the 1968/69 season. In the 1971/72 season, the Freshwater Fish Marketing Board would not accept Pigeon Lake lake whitefish because they were not of a commercial size. Buck Lake has produced a relatively stable commercial harvest of lake whitefish since 1942 with continuous use of 5½ (13.97 cm) inch stretched mesh gill nets. Since 1967, the commercial fishery in Buck Lake has been restricted to one lift due to the number of licenses issued for this fishery.

The total of all species of fish captured in gill net sets made in Pigeon and Buck Lake during the course of these studies is presented in table XVI. Walleyes were absent from the samples in Pigeon Lake and were last recorded in the Pigeon Lake commercial fishery in 1963/64. A total of 945 walleyes were captured in the gill net sets in Buck Lake set to capture lake whitefish over the three year sampling period. Only forty-three of a total of 771 walleyes were captured in the larger mesh sizes {3½ (8.89 cm) to 5½ (13.97 cm) inclusive} set in Buck Lake under ice cover. A total of seventeen northern pike were captured in Pigeon Lake as opposed to 431 captured in Buck Lake during the course of these studies. A total of 1349 white suckers were captured in Pigeon Lake and 138 captured in Buck Lake in gill net sets. The majority of the suckers were captured in the 3½ (8.89 cm) and 4 inch (10.16 cm) mesh nets in Pigeon Lake and the 4½ (11.43 cm) and 5 inch (12.70 cm) nets in Buck Lake.

The catch per unit effort of mature fish (IV+ and older), defined as the number of fish captured in a twenty-four hour set of one

TABLE XVI. Number of nine species of fish harvested in ten stretched measure mesh sizes in inches and centimeters (brackets) of gill nets set in open water (summer) and under ice cover (winter) in Pigeon Lake in 1968 to 1970 inclusive and Buck Lake in 1969 to 1971 inclusive. The total number of yards and hours fished for each mesh size in each of the two seasons in each lake is presented.

Lake/ Season	Species	Mesh									
		1.0 (2.54)	1.5 (3.81)	2.0 (5.08)	2.5 (6.35)	3.0 (7.62)	3.5 (8.89)	4.0 (10.16)	4.5 (11.43)	5.0 (12.70)	5.5 (13.97)
Pigeon/ Summer											
Total yds.		166	266	216	649	300	1400	1700	1250		
Total hrs.		165	187	184	313	99	477	623	470		
	L. whitefish	25	134	216	1718	626	2880	1716	670		
	N. pike	2	3	2	7	1	0	0	1		
	Walleye	0	0	0	0	0	0	0	0		
	W. sucker	0	6	14	129	102	601	394	103		
	Burbot	0	1	1	4	4	13	21	17		
	Y. perch	14	580	131	21	4	14	6	0		
	Trout-perch	243	0	1	2	0	0	0	0		
	Spottail Shiner	52	0	0	0	0	0	0	0		
	Emerald Shiner	38	0	0	0	1	0	0	0		
Winter											
Total yds.		---	---	---	---	---	1250	1500	150		
Total hrs.		---	---	---	---	---	516	580	64		
	L. whitefish						732	558	10		
	N. pike						0	1	0		
	Walleye						0	0	0		
	W. sucker						17	16	0		
	Burbot						7	16	0		
	Y. perch						2	1	0		
	Trout-perch						0	0	0		
	Spottail Shiner						0	0	0		
	Emerald Shiner						0	0	0		

cont.

TABLE XVI cont.

Lake/ Season	Species	Mesh 1.0 (2.54)	1.5 (3.81)	2.0 (5.08)	2.5 (6.35)	3.0 (7.62)	3.5 (8.89)	4.0 (10.16)	4.5 (11.43)	5.0 (12.70)	5.5 (13.97)
Buck/ Summer											
Total yds.		16.6	400	50	350	---	250	1250	1950	2150	2350
Total hrs.		16.5	110	34	134	---	85	419	669	706	712
	L. whitefish	0	5	39	124		123	468	684	691	655
	N. pike	1	0	31	30		29	21	11	253	3
	Walleye	2	2	115	55		30	316	226	120	36
	W. sucker	0	0	1	0		3	16	57	56	1
	Burbot	0	0	0	1		0	9	9	9	3
	Y. perch	7	0	21	4		33	3	0	2	0
	Trout-perch	0	0	0	0		0	0	0	0	0
	Spottail Shiner	0	0	0	0		0	0	0	0	0
	Emerald Shiner	0	0	0	0		0	0	0	0	0
Winter											
Total yds.		---	---	---	---	---	400	700	900	1450	2350
Total hrs.		---	---	---	---	---	172	301	379	613	537
	L. whitefish						17	36	116	119	406
	N. pike						20	13	12	3	4
	Walleye						1	15	12	13	2
	W. sucker						0	1	2	1	0
	Burbot						2	1	4	3	12
	Y. perch						7	4	2	2	0
	Trout-perch						0	0	0	0	0
	Spottail Shiner						0	0	0	0	0
	Emerald Shiner						0	0	0	0	0

hundred yards of gill net, eight feet in depth, was higher in the 3½ inch (8.89 cm) stretched mesh 210/3 nylon nets set during the open water period in Pigeon Lake than that of the 4 (10.16 cm) and 4½ inch (11.43 cm) nets (Table XVII). The four inch nets (10.16 cm) were more efficient than the 4½ (11.43 cm) inch nets. The catch per unit effort during the winter fishing in Pigeon Lake was lower in all three mesh sizes than that of the same mesh sizes during the open water period. During the winter fishing period, the 3½ inch (8.89 cm) and 4 inch (10.16 cm) net did not differ significantly in the catch per unit effort of mature fish but both these mesh sizes had a significantly higher efficiency than the 4½ inch (11.43 cm) mesh.

The 4½ (11.43 cm), 5 (12.70 cm), and 5½ inch (13.97 cm) mesh nets captured mature lake whitefish with equal efficiency in Buck Lake (Table XVII). The efficiency of the same three mesh sizes in Buck Lake was greater during the summer period than during the winter gill net fishing. The catch per unit effort of the 4½ (11.43 cm) and 5 inch (12.70 cm) nets during the winter fishing were not significantly different but the 5½ inch (13.97 cm) net was more efficient than either the other two nets under ice cover.

The 3½ (8.89 cm), 4 (10.16 cm), and 4½ inch (11.43 cm) stretched mesh gill nets in Pigeon Lake captured over 80 per cent mature lake whitefish (IV+ and older) whereas the 4½ (11.43 cm), 5 (12.70 cm), and 5½ inch (13.97 cm) stretched mesh gill nets captured over 80 per cent mature fish in Buck Lake (Table XVIII). The 2½ inch (6.35 cm) nets in Pigeon Lake and the 4 inch (10.16 cm) nets in Buck Lake capture 38.2 and 55.5 per cent immature fish (3 completed annuli or less) respectively.

TABLE XVII. Mean and range of catch per unit effort of gill net sets of mesh sizes that captured mature fish in Pigeon and Buck Lake in open water (summer) and under ice cover (winter). The number of overnight gill net sets of each mesh size in each season are indicated. Comparisons of means found highly significantly$_{.01}$ greater (>>) and non-significantly$_{.05}$ different (≃) are indicated.

Lake	Season	Statistic	Mesh Size				
Pigeon			3½" (8.89cm)		4" (10.16cm)		4½" (11.43cm)
	Summer	Mean	296.6	>>	142.2	>>	74.5
		Range	60.3-569.4		6.0-549.1		4.1- 156.8
		No. Sets	28		34		25
			∨∨		∨∨		∨∨
	Winter	Mean	(69.1	≃	45.1)	>>	7.9
		Range	14.3-262.6		10.2-200.4		2.0- 13.3
		No. Sets	26		28		3
Buck			4½" (11.43cm)		5" (12.70cm)		5½" (13.97cm)
	Summer	Mean	61.1	≃	52.7	≃	63.5
		Range	2.1-480.0		0.0-432.0		0.0-1248.0
		No. Sets	39		41		42
			∨∨		∨∨		∨∨
	Winter	Mean	(14.6	≃	9.7	<<	18.8
		Range	1.9- 24.0		0.0- 32.0		0.0- 37.3
		No. Sets	18		29		26

TABLE XVIII. Number of lake whitefish of six age classes captured in four mesh sizes in Pigeon Lake and four mesh sizes in Buck Lake. The total number of immature and mature fish captured in each mesh size is tabulated. Percentages appear in brackets.

Lake	Maturity		Number Annuli	Mesh (Stretched Measure - 210/3 Nylon)			
Pigeon				2½" (6.35cm)	3½" (8.89cm)	4" (10.16cm)	4½" (11.43cm)
	Immature		II	1	1	0	0
			III	20	21	5	3
		Total		21(38.2)	22(7.2)	5(1.8)	3(1.8)
	Mature		IV	13	101	62	13
			V	14	126	140	93
			VI	7	47	58	49
			VII+	0	8	10	12
		Total		34(61.8)	282(92.8)	270(98.2)	170(98.2)
Buck				4" (10.16cm)	4½" (11.43cm)	5" (12.70cm)	5½" (13.97cm)
	Immature		II	88	12	6	1
			III	32	21	13	1
		Total		120(55.5)	33(18.9)	18(11.7)	2(1.7)
	Mature		IV	15	31	17	6
			V	37	38	37	44
			VI	33	39	41	45
			VII+	11	34	41	22
		Total		96(44.5)	142(81.1)	136(88.3)	117(98.3)

Pigeon Lake has a larger population of mature lake whitefish per unit area than Buck Lake. The lake whitefish populations in both lakes are more active in open water during the summer than under ice cover in the winter (Table XIX). The average catch per unit effort of the three mesh sizes in Pigeon Lake is about three times that of Buck Lake in both the summer and winter fishing periods. The catch per unit effort during the summer period is about four times that of the winter in both Pigeon and Buck Lake.

h. Feeding and Food Abundance

The standing crop of bottom fauna in three surficial lake sediments sampled for a period of one year was higher in Buck Lake than in Pigeon Lake (Figure 14). In August, the number of invertebrates, the total of the three means of three samples in each substrate, was higher in the Pigeon Lake samples than the Buck Lake samples. The increased number of invertebrates in the Pigeon Lake samples was due to a large number of Tendipedidae found in the rubble samples. In March, the standing crop of invertebrates was higher in the Pigeon Lake samples due to a larger number of *Hyalella azteca* found in the sand substrate samples.

Buck Lake has a greater weight biomass of bottom fauna in the standing crop than Pigeon Lake throughout the twelve month sampling period (Figure 15). The amount of bottom fauna available in Buck Lake for bottom feeding lake whitefish is higher than Pigeon Lake throughout the winter months (October to April). The total number of invertebrates in the bottom samples taken in three surficial lake sediments of both lakes over a period of one year are presented in Appendix N.

TABLE XIX. Mean ($\bar{x}$) catch per unit effort, per cent mature fish in three mesh sizes and weighted mean catch per unit effort of mature fish in three mesh sizes set in open water (summer) and under ice cover (winter) in Pigeon and Buck Lake. The average catch per unit effort for each season in each lake is presented.

Season	Lake	Statistic	Mesh Size			Average
Summer	Pigeon		$3\frac{1}{2}''$ (8.89cm)	$4''$ (10.16cm)	$4\frac{1}{2}''$ (11.43cm)	
		$\bar{x}$	296.6	142.2	74.5	
		Per cent Mature	92.8	98.2	98.2	
		Weighted $\bar{x}$	275.2	139.6	73.2	162.7
	Buck		$4\frac{1}{2}''$ (11.43cm)	$5''$ (12.70cm)	$5\frac{1}{2}''$ (13.97cm)	
		$\bar{x}$	61.1	52.7	63.5	
		Per cent Mature	81.1	88.3	98.3	
		Weighted $\bar{x}$	49.5	46.5	62.4	52.8
Winter	Pigeon		$3\frac{1}{2}''$ (8.89cm)	$4''$ (10.16cm)	$4\frac{1}{2}''$ (11.43cm)	
		$\bar{x}$	69.1	45.1	7.9	
		Per cent Mature	92.8	98.2	98.2	
		Weighted $\bar{x}$	64.1	44.3	7.7	38.7
	Buck		$4\frac{1}{2}''$ (11.43cm)	$5''$ (12.70cm)	$5\frac{1}{2}''$ (13.97cm)	
		$\bar{x}$	14.6	9.7	18.8	
		Per cent Mature	81.1	88.3	98.3	
		Weighted $\bar{x}$	11.8	8.6	18.5	13.0

FIGURE 14. Mean standing crop of invertebrates of three samples of a six inch Ekman dredge in each of three surficial lake sediments in Pigeon and Buck Lake taken monthly over a twelve month period.

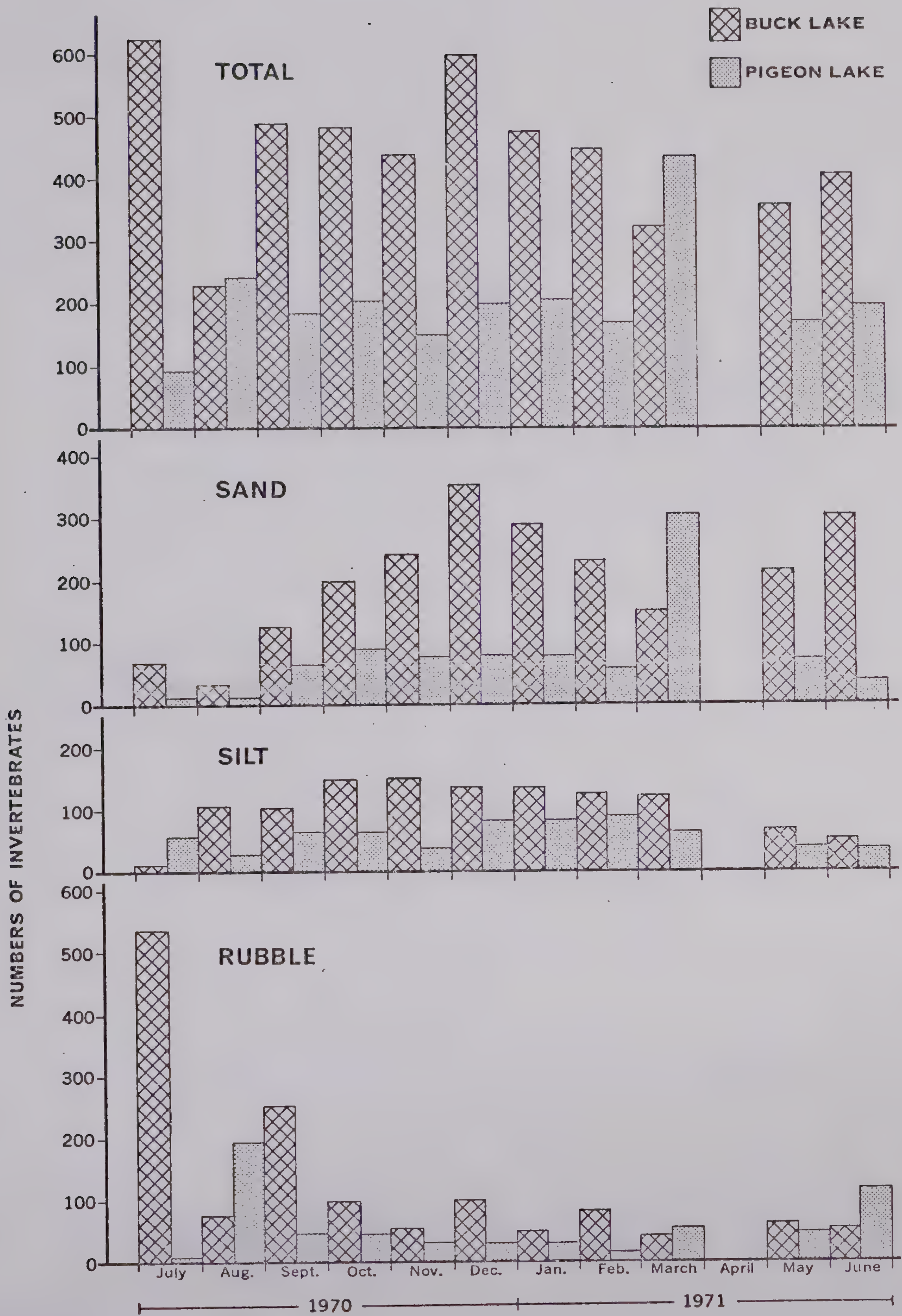
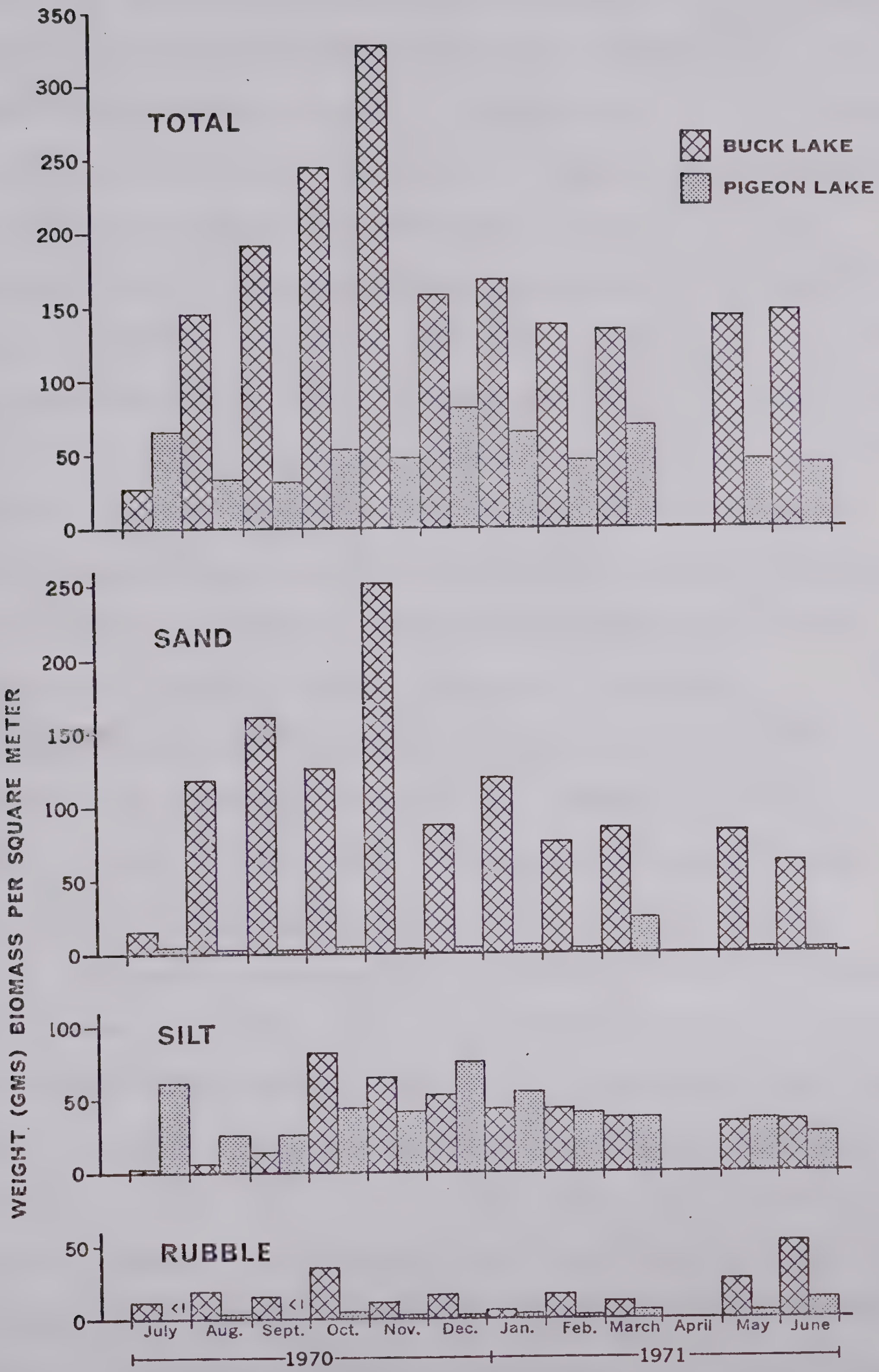

BUCK LAKE
PIGEON LAKE
TOTAL
SAND
SILT
RUBBLE
NUMBERS OF INVERTEBRATES
600
500
400
300
200
100
0
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
March
April
May
June
1970
1971

Figure 14

FIGURE 15. Mean weight biomass of the standing crop of invertebrates in three samples of a six inch Ekman dredge in each of three surficial lake sediments taken monthly over a twelve month period.



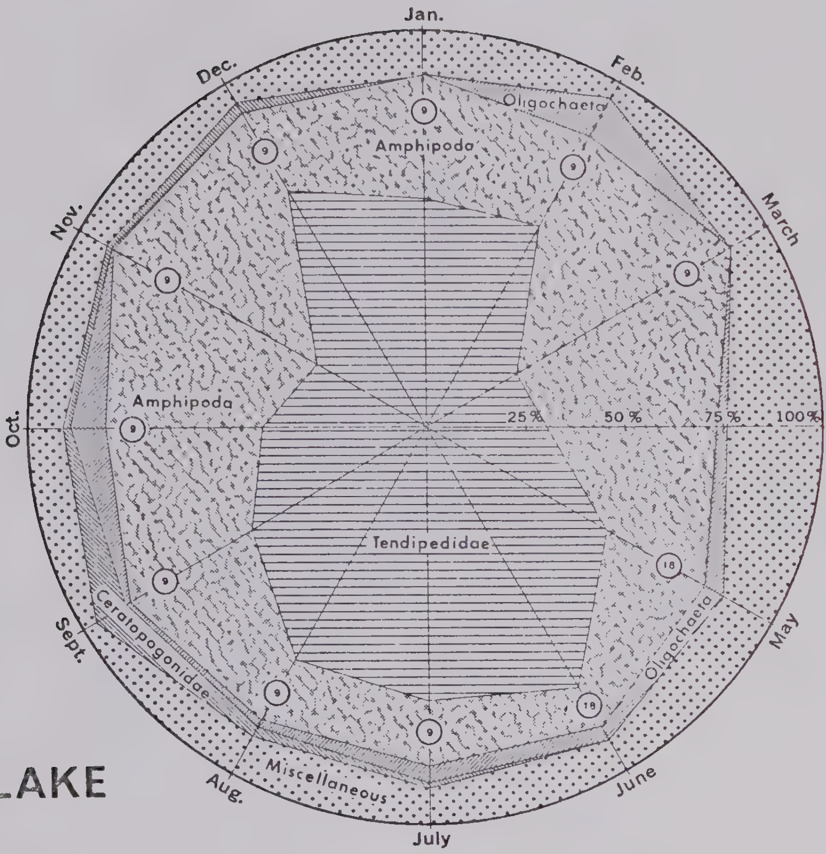
TOTAL
BUCK LAKE
PIGEON LAKE
SAND
SILT
RUBBLE
WEIGHT (GMS) BIOMASS PER SQUARE METER
350
300
250
200
150
100
50
0
<1
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
March
April
May
June
1970
1971

Figure 15

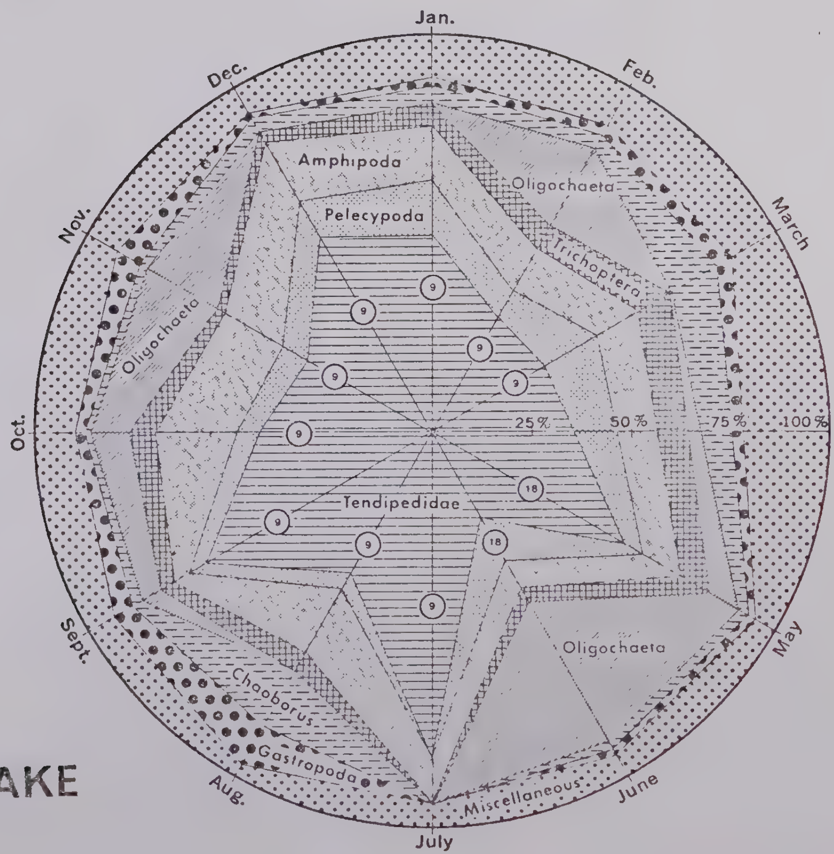
The percent contribution of invertebrates to the standing crop of bottom fauna in Pigeon and Buck Lake over a twelve month period is presented and compared in Figure 16. Tendipedidae was a major contributor to the bottom fauna of both lakes whereas Oligochaeta has a greater prominence in the samples from Buck Lake than Pigeon Lake. Both Pelecypoda and Gastropoda were prominent in the Buck Lake samples but were a miscellaneous contributor (less than five percent) to the total of the Pigeon Lake samples. Other invertebrates that contributed less than five percent to the total number in Pigeon Lake were Coleoptera, Chaoborinae, Nematoda, Hirudinea, Ephemeroptera, Corixidae, Hydra, Hydracarina, Ostracoda, and Trichoptera. Miscellaneous invertebrates (<5 percent) found in the Buck Lake samples included Ceratopogonidae, Hirudinea, Ephemeroptera, Corixidae, Hydra, Hydracarina, and Nematoda. The total number of invertebrates found in the three surficial lake sediments is presented in the appendices (Appendix N). *Gammarus l. lacustris* was noticeably absent from the Pigeon Lake samples and present, though in a lower abundance, than *Hyalella azteca* in the Buck Lake samples.

The percent contribution of food items to the diet of twenty-five millimeter size class ranges of lake whitefish differs between the Pigeon and Buck Lake samples (Figure 17). Cladocera was a major food item of the smaller fish in Pigeon Lake (101 to 200 mm) but small sample sizes in the ranges between 151 and 200 mm could account for these findings. Cladocera was a prominent food item in the Buck Lake fish and less prominent in the Pigeon Lake fish. Copepoda was more prominent in the diet of Pigeon Lake fish of 251 to 425 mm but only a miscellaneous (<5 percent) food item in the Buck Lake samples of the same size. Fish eggs were a major contributor to the diet of mature Pigeon Lake fish

FIGURE 16. Percent contribution of invertebrates to the standing crop samples from Pigeon and Buck Lakes taken over a twelve month period. The number of six inch Ekman samples comprising each monthly sample is presented on the radii.



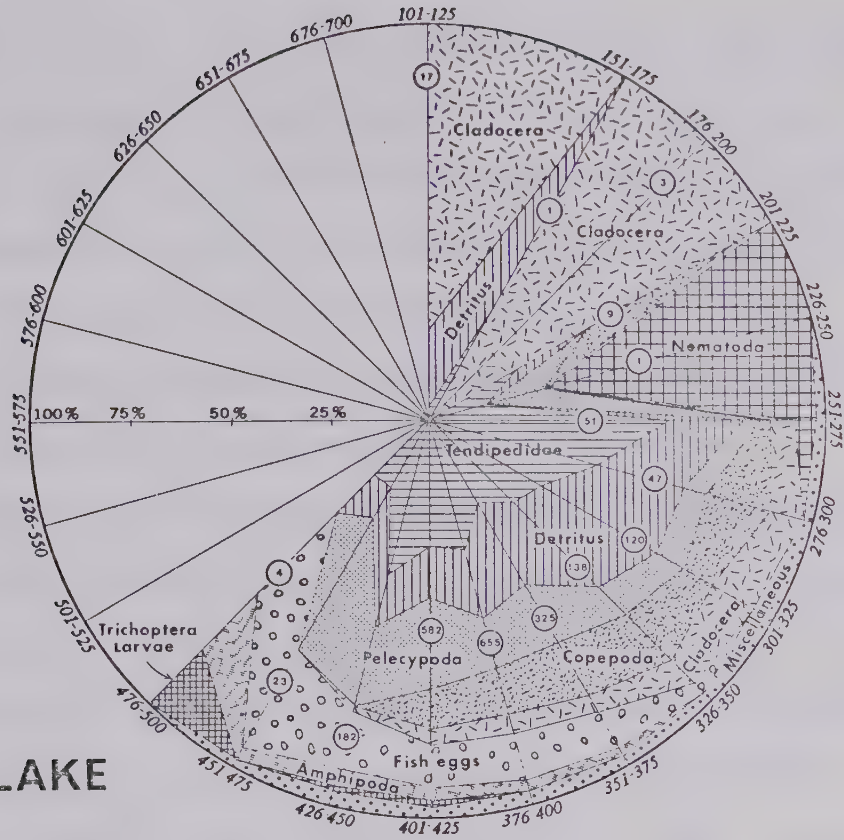
PIGEON LAKE



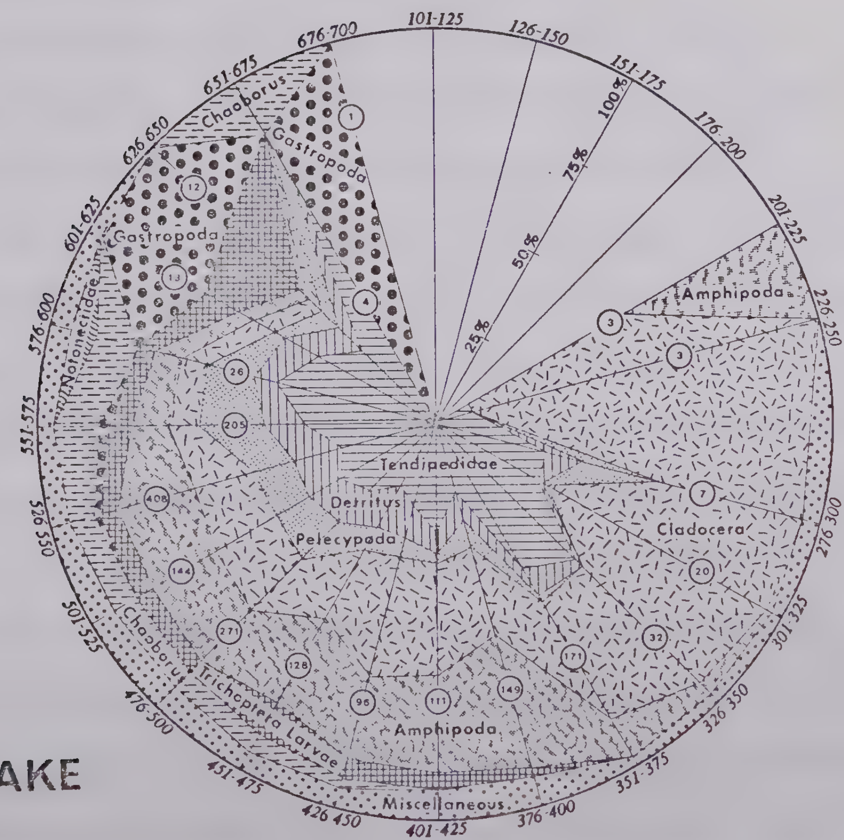
BUCK LAKE

Figure 16

FIGURE 17. Percent contribution of food items to the total volume of food in the diet of twenty-four lake whitefish fork length size class ranges from Pigeon and Buck Lake. The sample size of each size class is presented on the radii.



PIGEON LAKE



BUCK LAKE

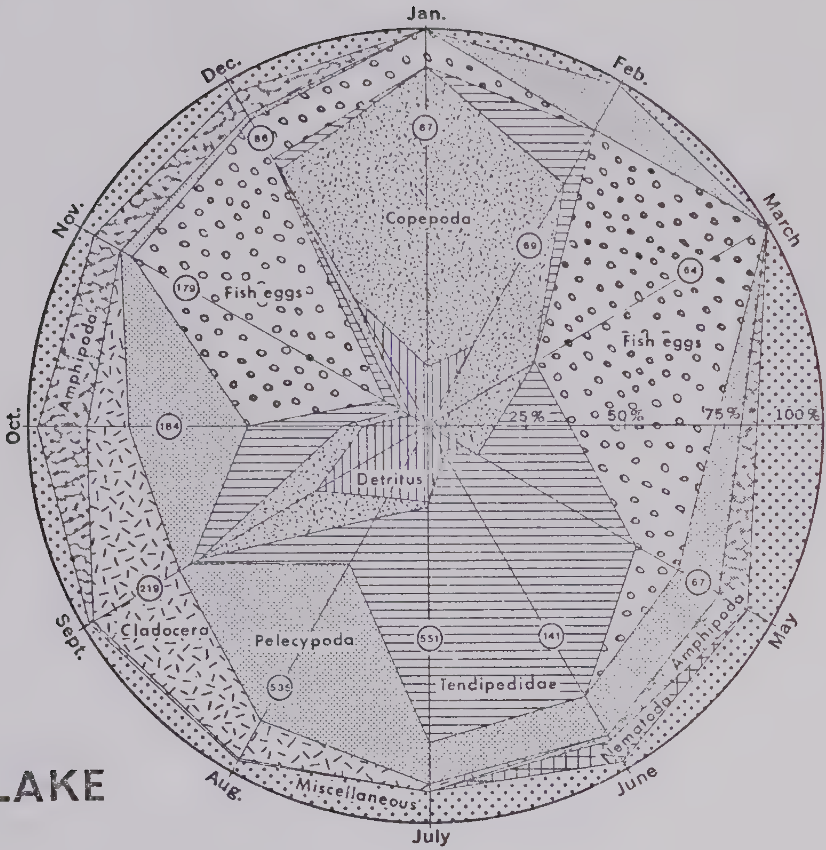
Figure 17

(350 to 500 mm) but only a minor food item (<5 percent) of all sizes of Buck Lake fish sampled. Other miscellaneous food items found in the Buck Lake fish stomachs were Hydracarina, Ephemeroptera, Ceratopogonidae, Copepoda, Corixidae, Hirudinea and Coleoptera. Miscellaneous (<5 percent) food items in the Pigeon samples were Hydracarina, Gastropoda, Ephemeroptera, Ceratopogonidae, fish remains, Chaoborinae, Corixidae, Hirudinea, Coleoptera, Oligochaeta and adult Tendipedidae.

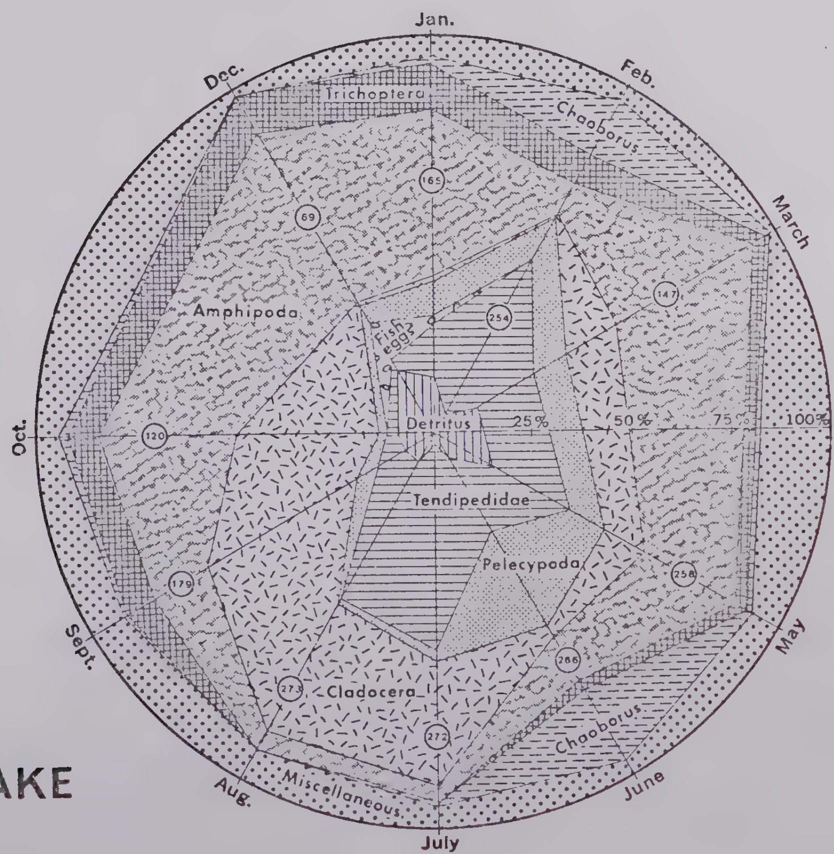
The percent contribution of food items to the diet of Pigeon Lake lake whitefish differed from that of Buck Lake fish when examined over a twelve month period (Figure 18). Lake whitefish eggs were a major contributor to the diet of Pigeon Lake whitefish from October to January whereas burbot eggs were a major food item in the Pigeon Lake fish from March to May. Lake whitefish eggs made a small contribution to the diet of Buck Lake lake whitefish in December and January only. Amphipoda and Pelecypoda were more prominent in the diet of Buck Lake fish than Pigeon Lake fish throughout the year. Copepoda was a prominent food item in the diet of Pigeon Lake fish from December to May but only a minor contributor to the diet of Buck Lake fish during the same period. Cladocera became a prominent prey of Buck Lake fish in July to October and was less prominent in the diet of Pigeon Lake fish during the same period of time. Tendipedidae were prominent in the diet of Buck Lake fish throughout the year but were only a major contributor to the diet of Pigeon Lake fish during the summer months (May to October).

The standing crop of bottom fauna differed from the feeding habits of the Pigeon Lake lake whitefish population when compared over a twelve month period (Figure 19). Fish eggs contributed less than five percent to the bottom fauna samples yet were a major food item

FIGURE 18. Percent contribution of food items to the diet of Pigeon and Buck Lake yearling and older lake whitefish over a twelve month period. The monthly sample size is presented on the radii.



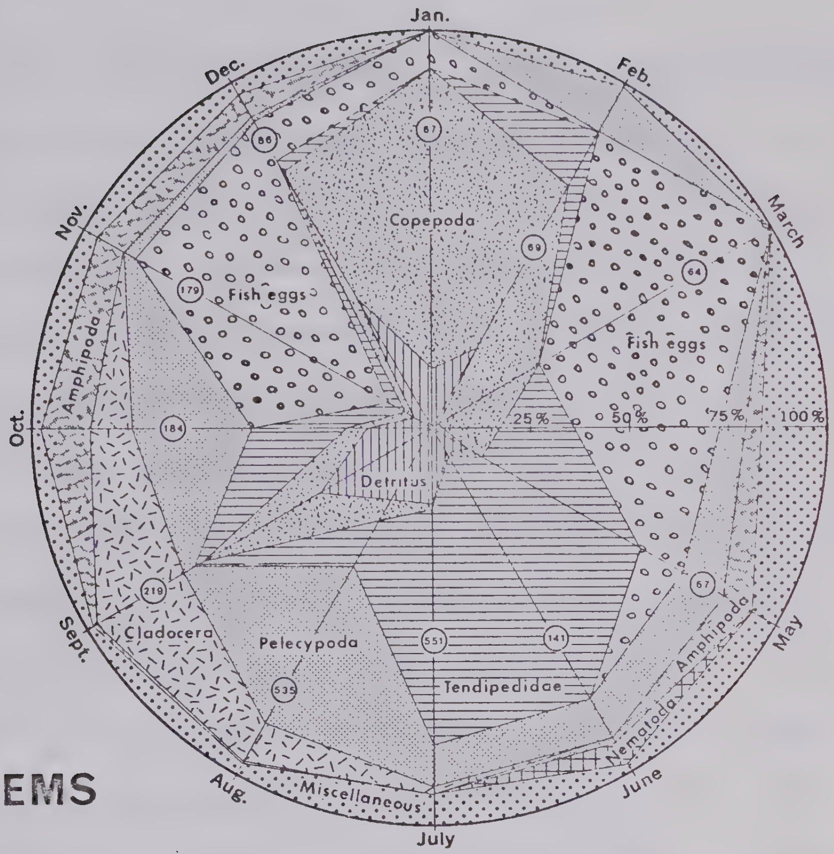
PIGEON LAKE



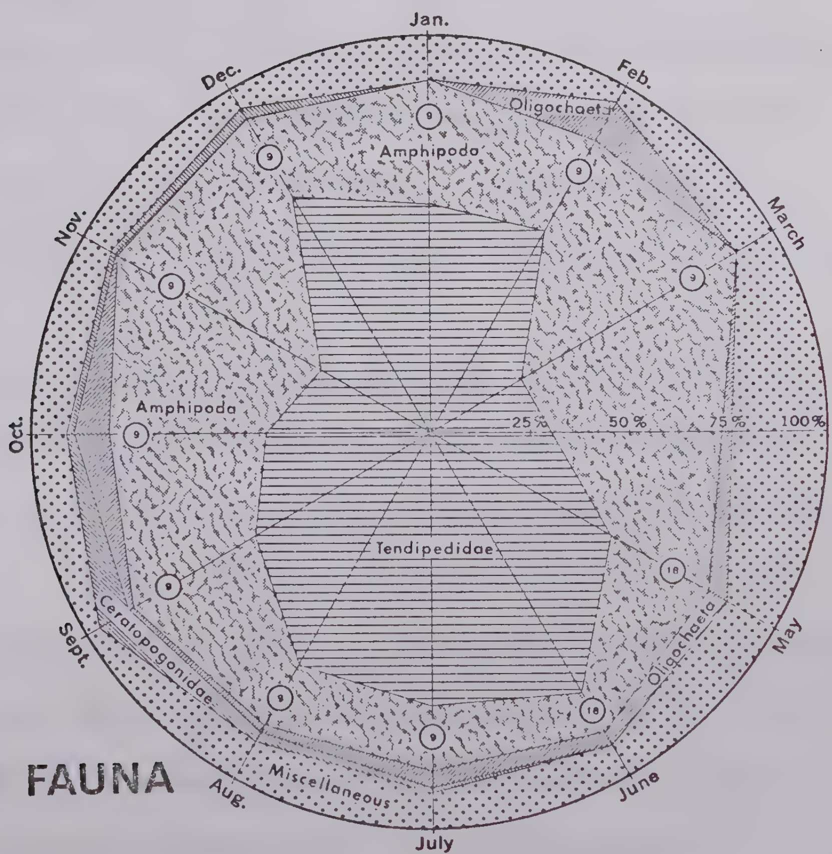
BUCK LAKE

Figure 18

FIGURE 19. Percent invertebrates in the standing crop of bottom fauna in Pigeon Lake and the percent contribution of food items to the diet of Pigeon Lake yearling and older lake whitefish over a twelve month period. The monthly sample size is presented on the radii.



FOOD ITEMS



BOTTOM FAUNA

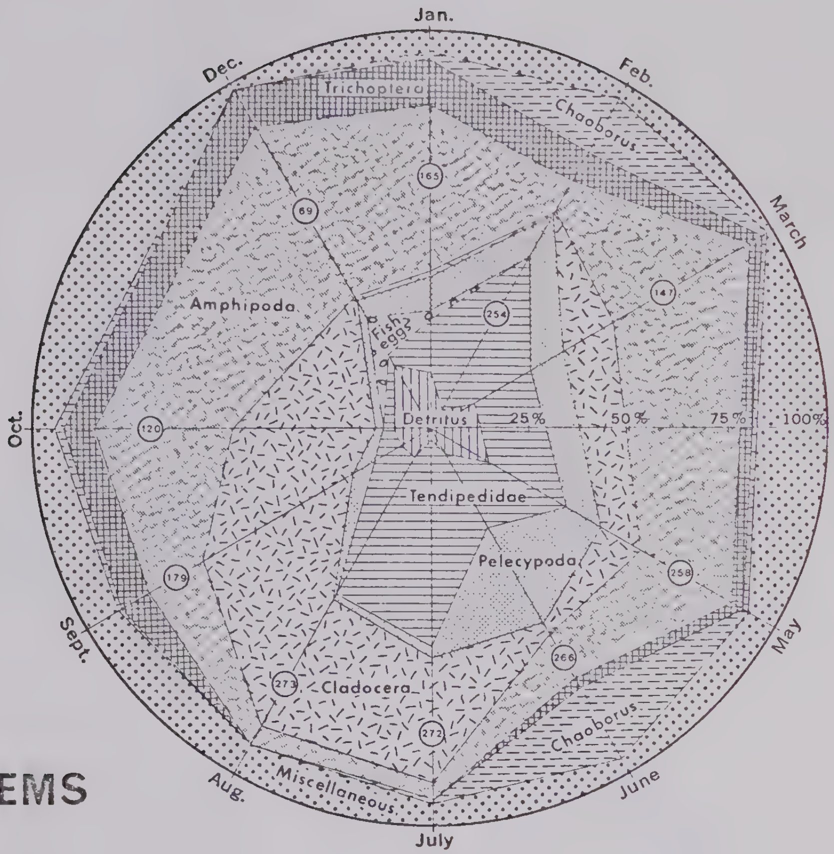
Figure 19

of the diet of the fish. Although Tendipedidae were a major contributor to the standing crop of bottom fauna in November to January, they were not consumed to any extent by the whitefish at this time. Although amphipods, *Hyalella azteca* were present in the bottom fauna samples throughout the year they only made a noticeable contribution (>5 percent) to the diet of Pigeon Lake whitefish in May.

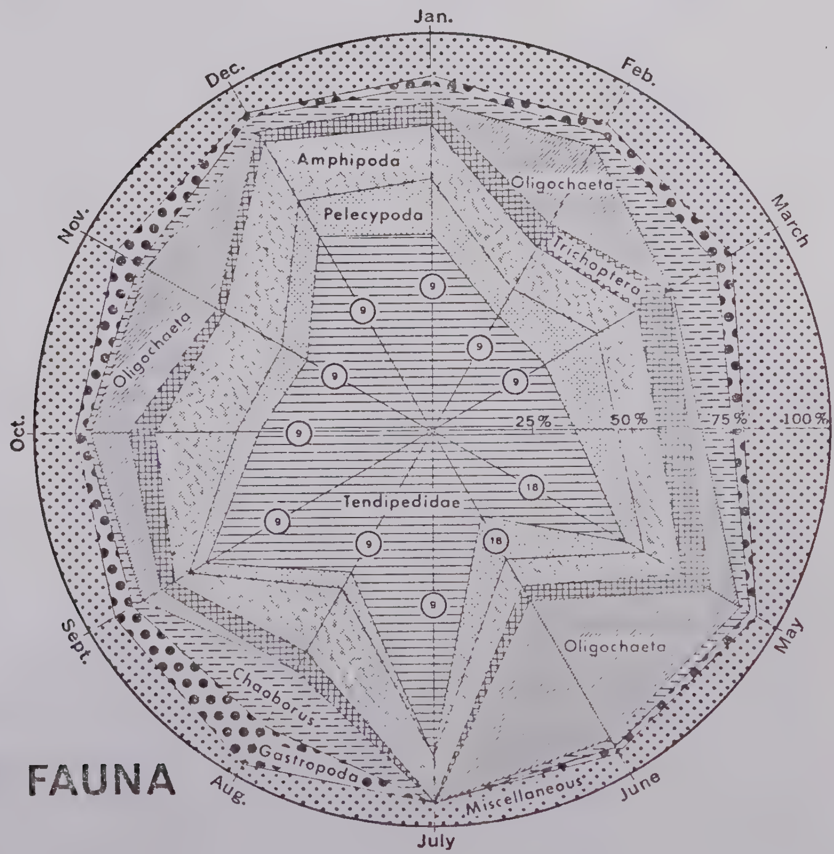
The bottom fauna available to the Buck Lake whitefish differed from that consumed by the Buck Lake lake whitefish (Figure 20). Although Oligochaeta were prominent in the Buck Lake bottom fauna samples, they were not a prominent food item in the diet of Buck Lake fish. Pelecypoda made relatively the same contribution to the diet of the fish as they occurred in the standing crop samples. Cladocera became a major food item of the fish in July to October even though bottom fauna was available at the time. Fish eggs were of minor importance in the standing crop samples in December (<5 percent) yet contributed significantly to the food of Buck Lake lake whitefish in December. Trichoptera exhibited a similar prominence in the diet as in the bottom fauna samples throughout the year.

The standing crop of zooplankton in Pigeon Lake was lower than that of Buck Lake when sampled simultaneously over a thirteen month period (Figure 21). With the exception of two sampling periods, the standing crop of Copepoda in Pigeon Lake was lower than that of Buck Lake. The standing crop of Cladocera was higher in Buck Lake than Pigeon Lake in all but one of the thirteen sampling periods. A pulse in the standing crop of Cladocera occurred in Buck Lake beginning in August, peaking in October and declining in November and again in December. No such pulse was evident in Pigeon Lake during the same

FIGURE 20. Percent invertebrates in the standing crop of bottom fauna in Buck Lake and the percent contribution of food items to the diet of Buck Lake yearling and older lake whitefish over a twelve month period. The monthly sample size is presented on the radii.



FOOD ITEMS



BOTTOM FAUNA

Figure 20

FIGURE 21. Mean number of Cladocera and Copepoda per unit volume of water in samples collected at three depth strata in Pigeon and Buck lakes over a thirteen month sampling period.

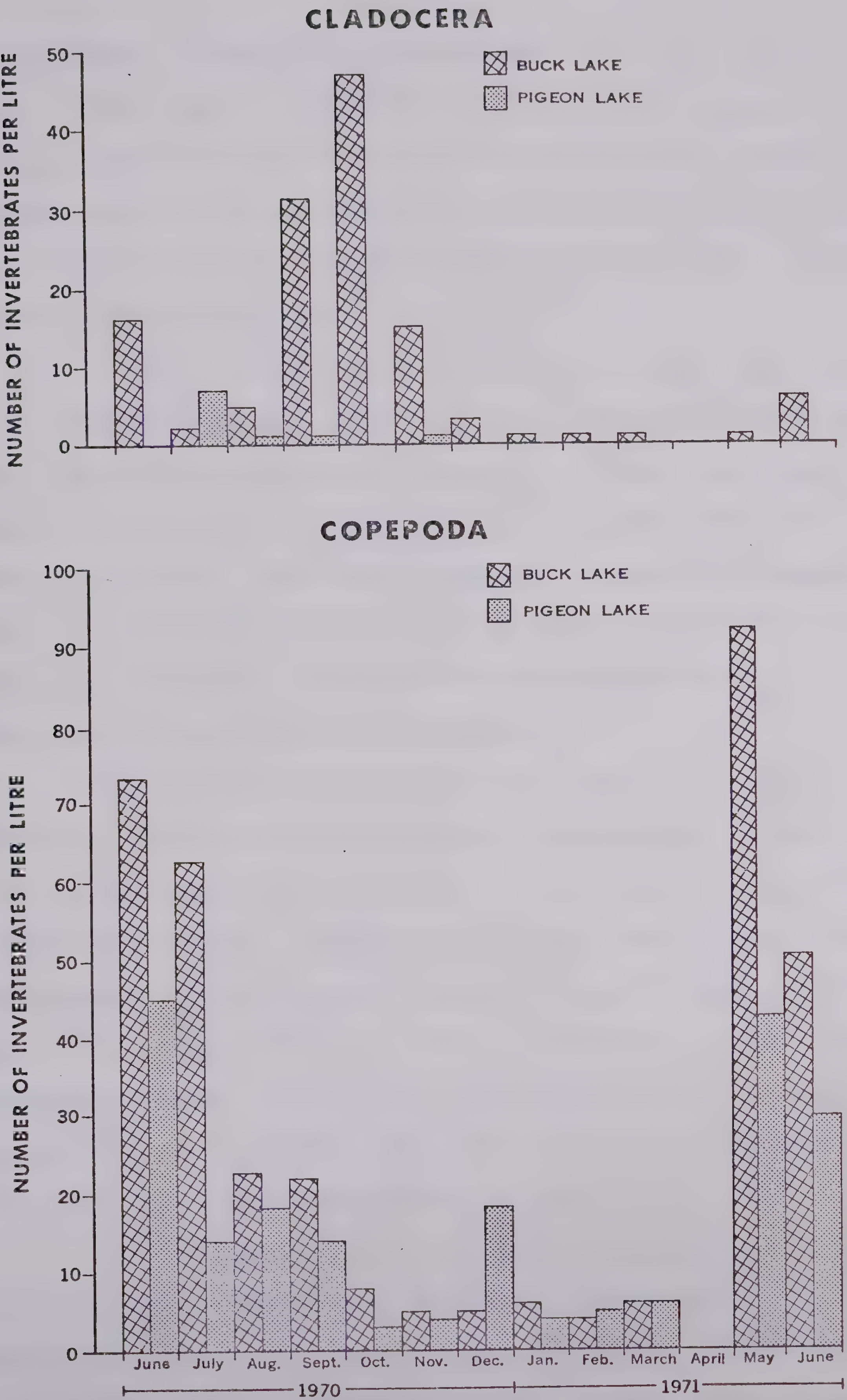

CLADOCERA
BUCK LAKE
PIGEON LAKE
NUMBER OF INVERTEBRATES PER LITRE
0
10
20
30
40
50
COPEPODA
BUCK LAKE
PIGEON LAKE
NUMBER OF INVERTEBRATES PER LITRE
0
10
20
30
40
50
60
70
80
90
100
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
March
April
May
June
1970
1971

Figure 21

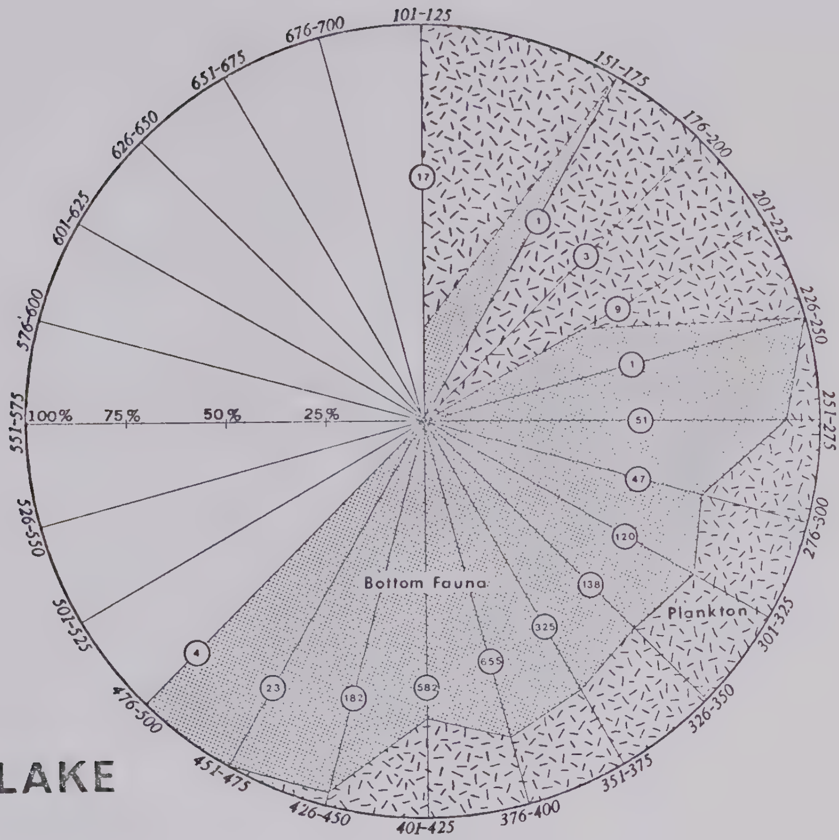
period of time. *Cyclops bicuspidalus thomasi* Forbes was the most common copepod noted in the samples from both lakes. *Diaptomus sp.* was less common but found in the samples from both lakes. *Daphnia similis,* Claus was the most common species of Cladocera noted in the samples from both lakes. *Leptodora kindti* (Focke) was noted as present in both these eutrophic lakes.

The percent contribution of plankton and bottom fauna to the diet of the different fork length size class ranges was similar between the Pigeon and Buck Lake samples (Figure 22). Plankton consisted of Cladocera and Copepoda. Plankton was a more prominent food item of the smaller fish in both lakes with the exception of one stomach sample from the 151-175 mm fork length size class range in Pigeon Lake. In both lakes, the diet of the larger fish was composed of about 75 percent bottom fauna and 25 percent plankton.

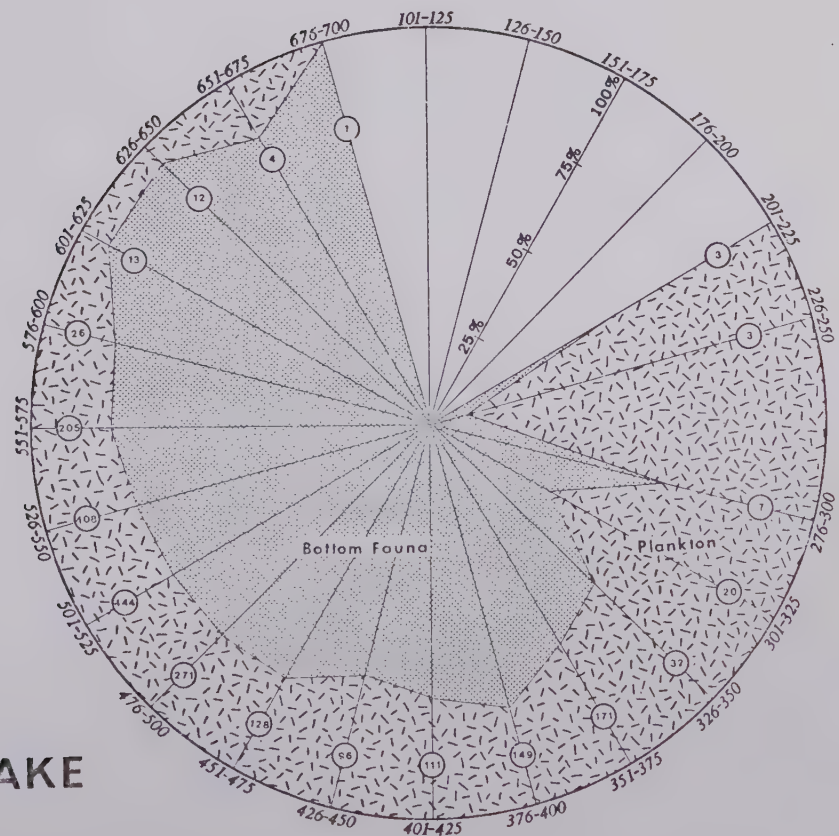
The contribution of planktonic food items to the diet of Pigeon Lake whitefish differed from that of Buck Lake when examined over a twelve month period (Figure 23). Planktonic items consisted of Cladocera and Copepoda. Plankton was the major food of Pigeon Lake lake whitefish over the winter months (December to March) whereas bottom fauna was the major food of Buck Lake fish throughout the winter months (December to March). Plankton was a more prominent food item in the diet of Buck Lake fish in the open water period (May to October) than Pigeon Lake fish during the same period of time.

The feeding habits of y-o-y lake whitefish populations from Pigeon Lake paralleled that of Buck Lake during their first year of life (Figure 24). Both Buck Lake and Pigeon Lake y-o-y lake whitefish fed mainly on plankton (Cladocera, Copepoda, aerial insects)

FIGURE 22. Percent contribution of planktonic food and benthic food to the total volume of food in samples of twenty-four length size class ranges of lake whitefish from Pigeon and Buck Lake. The sample size of each size class is presented on the radii.



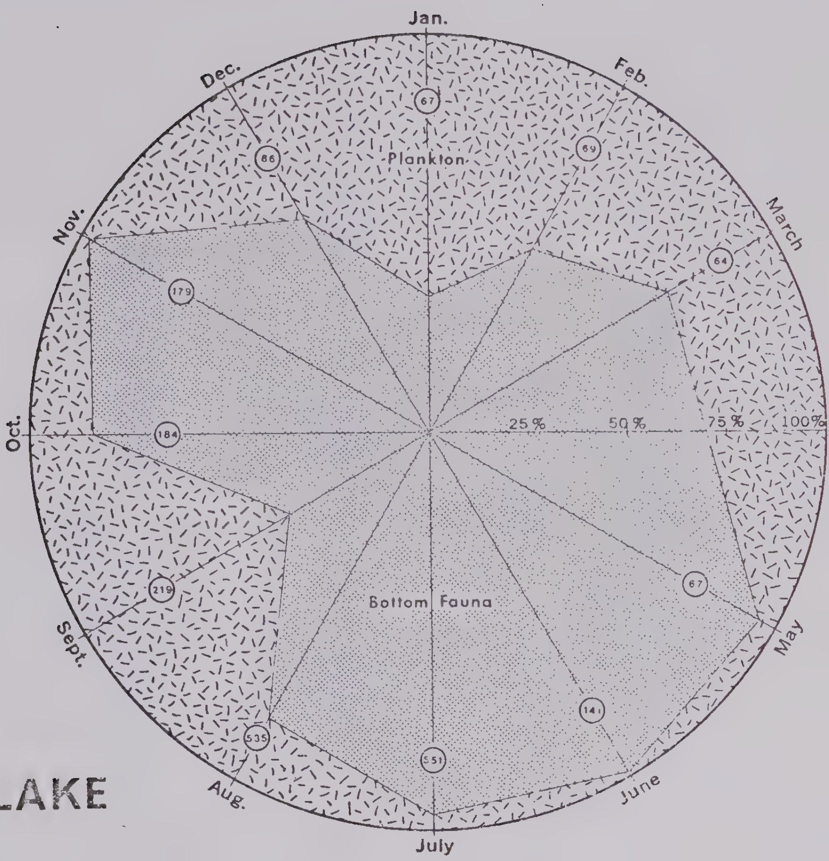
PIGEON LAKE



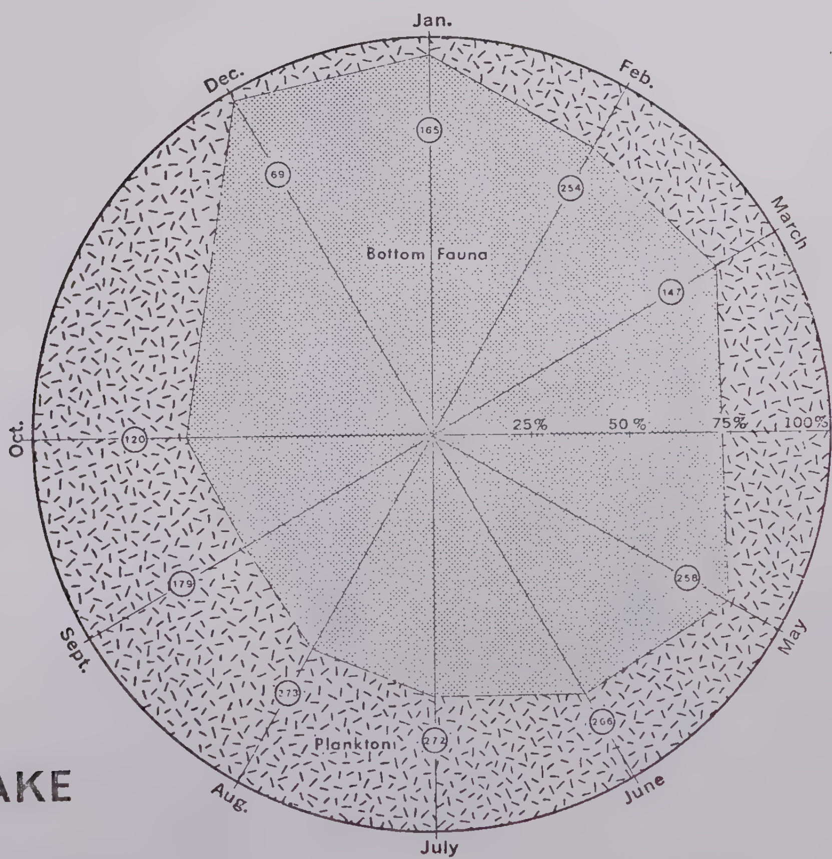
BUCK LAKE

Figure 22

FIGURE 23. Percent contribution of planktonic food and benthic food to the total volume of food in samples of yearling and older lake whitefish collected over a twelve month period in Pigeon and Buck Lake. The monthly sample size is presented on the radii.



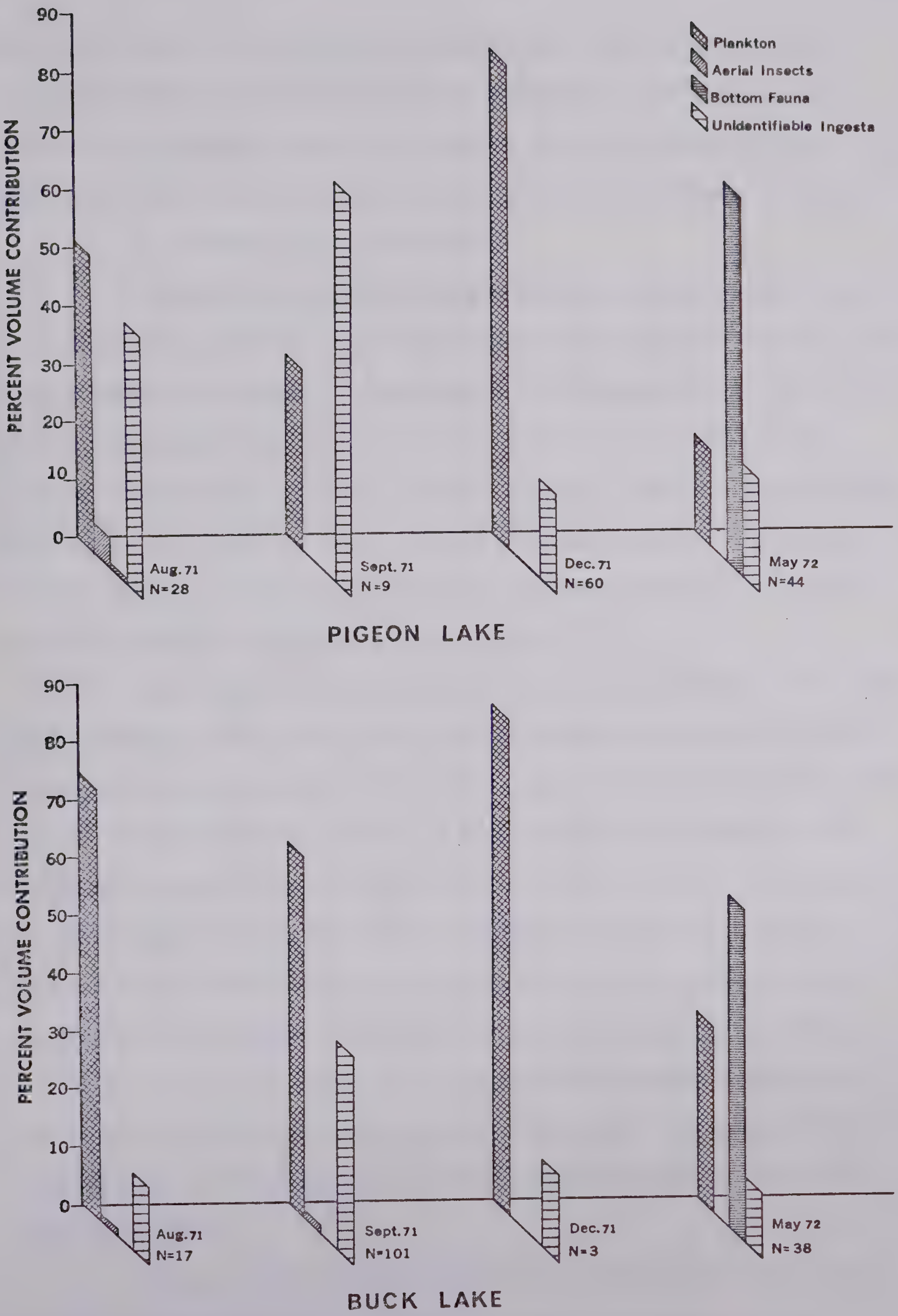
PIGEON LAKE



BUCK LAKE

Figure 23

FIGURE 24. Feeding habits of Pigeon and Buck Lake young-of-the-year lake whitefish in the summer and winter of their first year of life and feeding habits of yearling fish in the spring.



Plankton
Aerial Insects
Bottom Fauna
Unidentifiable Ingesta
PERCENT VOLUME CONTRIBUTION
90
80
70
60
50
40
30
20
10
0
Aug. 71
N=28
Sept. 71
N=9
Dec. 71
N=60
May 72
N=44
PIGEON LAKE
PERCENT VOLUME CONTRIBUTION
90
80
70
60
50
40
30
20
10
0
Aug. 71
N=17
Sept. 71
N=101
Dec. 71
N=3
May 72
N=38
BUCK LAKE

Figure 24

during the summer months (August to September). Both populations of young fish fed on planktonic organisms (Copepoda, Cladocera) during their first winter of life. After the ice left both lakes, the now yearling fish changed to a diet consisting primarily of bottom fauna.

2. Predators and Competitors

The walleye in Buck Lake are a predator of the younger age classes of lake whitefish. Both young-of-the-year (0+) and yearling (1+) lake whitefish were found in the stomachs of these predators. Walleye also fed on spottail shiners, burbot, yellow perch, northern pike, sticklebacks and young walleye. Walleye were not found present in Pigeon Lake during the course of these studies but were reported in the commercial harvest records of Pigeon Lake up to and including 1963/64 and reported as being present in the lake by Miller (1956).

Buck Lake could have suitable, tributary, spawning streams for walleye whereas Pigeon Lake with no large permanent tributary streams flowing into the lake, could lack suitable walleye spawning habitat. The lack of suitable spawning habitat in Pigeon Lake could account for the demise of the walleye population. A fyke net and gill nets set across the three major tributary streams in Buck Lake revealed that northern pike and white suckers were on a spawning migration up these streams in the spring. No walleyes were captured in these sets of nets. Walleyes were observed spawning in the spring on the same spawning beds used by lake whitefish in the fall in Buck Lake (Figure 6). The lake whitefish spawning beds in Pigeon Lake likely offer suitable spawning habitat for walleyes to spawn.

Northern pike are a predator of lake whitefish. The size and age class of lake whitefish consumed by pike was dependent on the

size of the predator. Northern pike are more abundant in Buck Lake than in Pigeon Lake (Table XVI). Northern pike were also predators of yellow perch, burbot, northern pike, and spottail shiners in Buck Lake. Burbot, as well as being predators of lake whitefish (0+ and I+), preyed on yellow perch, sticklebacks, and burbot.

Competitors of lake whitefish for bottom fauna in Pigeon Lake were trout-perch, emerald shiners, spottail shiners, yellow perch and white suckers. With the exception of emerald shiners and the addition of brook sticklebacks, the same competitors were present in Buck Lake (Table XIV).

III. Species and Abundance of Rooted Aquatic Plants

The density and species of rooted aquatic plants in Pigeon Lake (Figure 25) was less and fewer than that observed in Buck Lake (Figure 26) in July of the same year. Rooted aquatic plants were found to occur in Pigeon and Buck Lake up to a depth of seven feet (2.13 m) of water. The ten foot contour (3.05 m) in Pigeon Lake occupies 4,176 acres (1690.0 ha) or about 17.6 percent of the total lake area. In Buck Lake, the 1,727 acres (698.9 ha) of ten foot (3.05 m) contour occupies 28.1 percent of the total area of the lake. Only about 23.4 percent of the ten foot (3.05 m) contour in Pigeon Lake has rooted aquatic plants whereas 82.5 percent of the ten foot (3.05 m) contour in Buck Lake has rooted aquatic plants.

Between 1950 and 1966, the number of shoreline cottages on Pigeon Lake had increased from 250 to 845 units whereas on Buck Lake the number had increased from eight to twenty-nine over the same period of time (Table XX). Buck Lake has only about 4 miles less shoreline than

FIGURE 25. Location and concentration of seven species of rooted, perennial, aquatic plants in the littoral zone of Pigeon Lake.

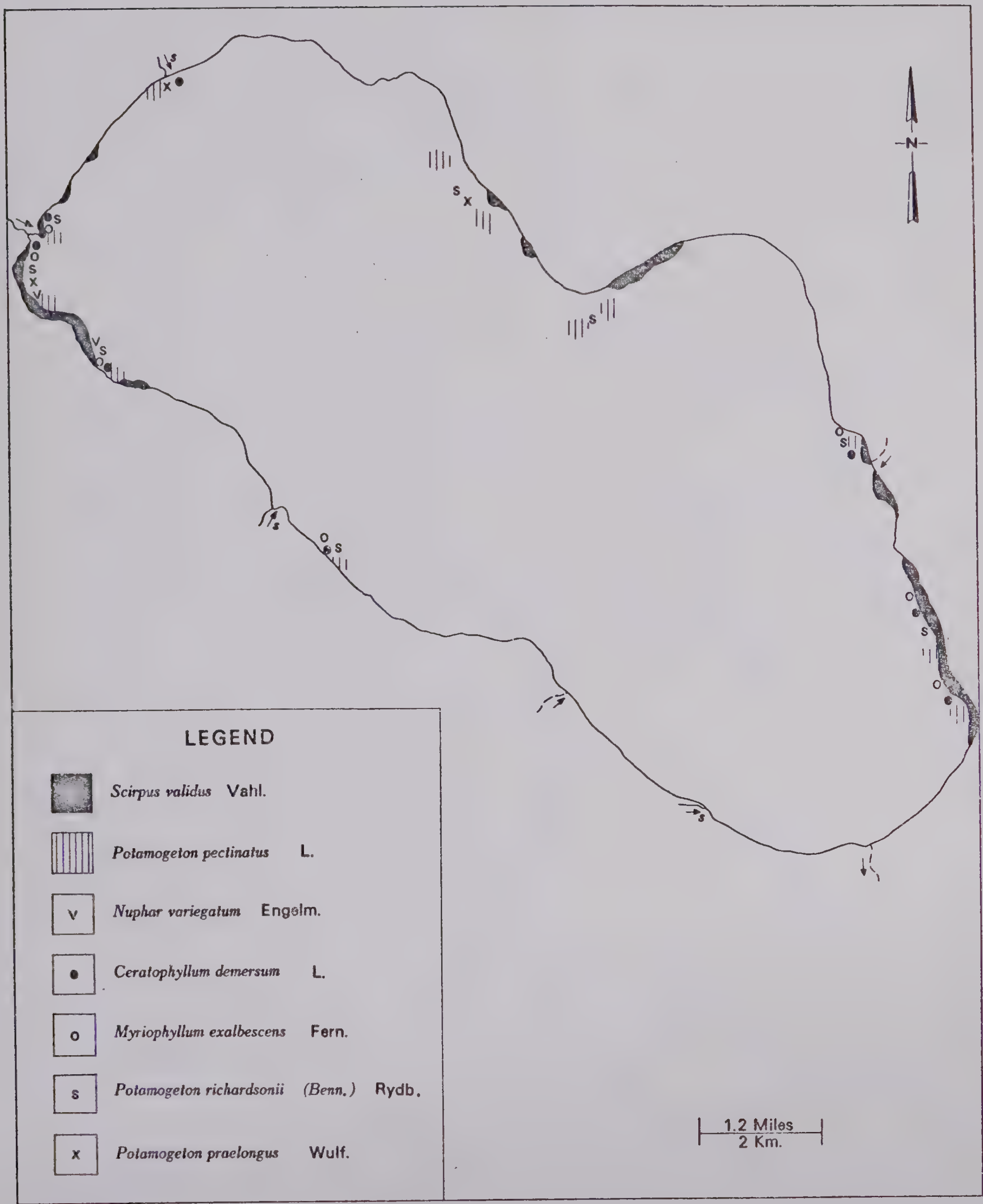

N
LEGEND
Scirpus validus Vahl.
Potamogeton pectinatus L.
v Nuphar variegatum Engelm.
Ceratophyllum demersum L.
o Myriophyllum exalbescens Fern.
s Potamogeton richardsonii (Benn.) Rydb.
x Potamogeton praelongus Wulf.
1.2 Miles
2 Km.

Figure 25

FIGURE 26. Location and concentration of eight species of rooted, perennial aquatic plants in the littoral zone of Buck Lake.

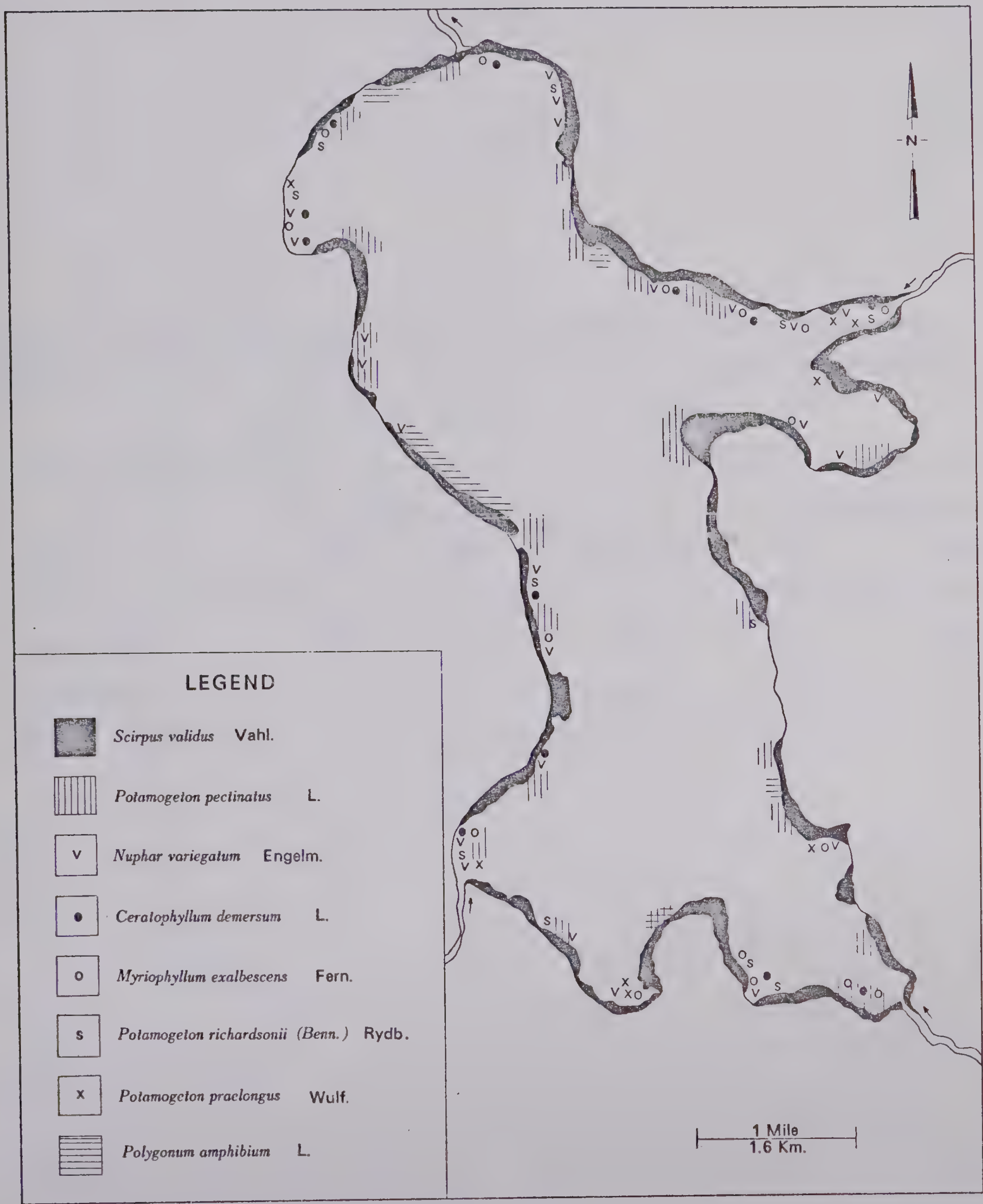

LEGEND
Scirpus validus Vahl.
Potamogeton pectinatus L.
Nuphar variegatum Engelm.
Ceratophyllum demersum L.
Myriophyllum exalbescens Fern.
Potamogeton richardsonii (Benn.) Rydb.
Potamogeton praelongus Wulf.
Polygonum amphibium L.
N
1 Mile
1.6 Km.

Figure 26

TABLE XX. Increase in the number of shoreline cottages on Pigeon and Buck Lakes over a sixteen year period. The average number of cottages per mile of shoreline is presented.

Lake	Year 1950	Year 1966	Miles of Shoreline	Average 1950	Average 1966
Pigeon Lake	250	845	26.4	9.47	32.0
Buck Lake	8	29	21.2	0.37	1.37

Pigeon Lake. In 1966, Pigeon Lake had an average of 32 cottages per mile of shoreline and Buck Lake had an average of only 1.37 cottages per mile of shoreline. The extent of cottage development on shoreline lots was positively correlated with littoral zones devoid of emergent aquatic plants. Removal of emergent aquatic plants with aquatic herbicides and/or by mechanical means was observed in both lakes during the course of these studies.

DISCUSSION

I. Divergence in Growth

Divergence in growth between Pigeon Lake and Buck Lake lake whitefish populations begins during the winter months of their first year of life (Figure 13). The population of lake whitefish in both Pigeon and Buck lakes produce the same size fish emerging from eggs (Table XI), have similar growth rates throughout the first summer but diverge in growth during the first winter (Table XIII). During the first summer and the first winter, young-of-the-year lake whitefish in both lakes are predominantly plankton feeding. In May of the following spring both populations of now yearling fish begin feeding on bottom fauna (Figure 24). Buck Lake young-of-the-year fish are plankton feeding during their first winter (Figure 24) but yearling and older fish are predominantly bottom feeding during the winter months (Figure 23). Pigeon Lake young-of-the-year are plankton feeding during the first winter but are in direct competition for food with the yearling and older Pigeon Lake lake whitefish that are also plankton feeding (Figure 23). Buck Lake has a higher standing crop

of plankton throughout the winter months than Pigeon Lake (Figure 21). Cropping of the plankton by the total Pigeon Lake population and cropping of the plankton by only the y-o-y Buck Lake population likely accounts for the higher standing crop of plankton in Buck Lake.

Although Pigeon Lake and Buck Lake are located in the same major drainage basin, are located at the same latitude (Figure 1), have similar morphometry (Figure 2 and 3) and have similar temperature (Figure 4) and dissolved oxygen (Figure 5) regimes, they support lake whitefish populations with dissimilar growth rates (Table II). The Buck Lake population of this species has sustained a similar growth pattern since 1954 whereas the growth rate of the Pigeon Lake population has declined over the same period of time (Table I and Table XV). Pigeon Lake supports about three times the number of mature individuals per unit areas as Buck Lake (Table XIX). Reduction in the size of the predator population in Pigeon Lake has likely caused the decline in the growth rate of the lake whitefish population by reducing the predation mortality of lake whitefish and other prey species and increasing the interspecific and intraspecific competition for the available food.

The optimum spawning habitat for northern pike is a bottom with a dense mat of short vegetation. This vegetation acts as both a stimulus to northern pike spawning and serves as a substrate for the attachment of spawned and fertilized eggs. The hatching young-of-the-year pike attach themselves by means of a sticky secretion of the head to plants and debris. The progeny remain in this belt of dense vegetation in shallow water for the available food supply and protection from predators. Outside this belt of dense vegetation young pike would experience increased mortality (Fabricus and Gustafson, 1958; Clark, 1950; Forney, 1968).

Northern pike, a predator of lake whitefish, are present in

larger numbers in Buck Lake than Pigeon Lake (Table XVI). An increase in summer cottage development on shoreline lots on Pigeon Lake since 1950 (Table XX) accompanied by clearing of rooted aquatic plants (Figure 25) has reduced the spawning and recruitment habitat for northern pike. Limited cottage development (Table XX) and clearing of rooted aquatic plants (Figure 26) has taken place on Buck Lake within this same period of time. Spawning and recruitment habitat for northern pike on Buck Lake is extensive.

Removal of rooted aquatic plants by cottage owners on Pigeon Lake has reduced spawning and recruitment habitat for northern pike and decreased predation by this species on lake whitefish and other species. The yearly recruitment of lake whitefish and other prey species has likely increased both the interspecific and intraspecific competition for food and reduced the growth rate of the lake whitefish population. Brynildson (1958) documented the effect of increased shoreline clearing on the decrease in the northern pike populations in Wisconsin Lakes. The reduction in this predator population created an overpopulated and stunted panfish (Centrarchidae) prey population.

The growth rate of the Buck Lake lake whitefish population was greater than that of the Pigeon Lake population in 1956 (Table I). Buck Lake with a shore development ratio of 1.98 likely had greater spawning and recruitment habitat for northern pike and a larger predator population per unit area at that time than Pigeon Lake with a shore development ratio of only 1.19. In addition, cottage development and clearing of habitat for and a reduction in the number of northern pike likely had begun prior to 1956 on Pigeon Lake. The growth rate

of the lake whitefish population was likely declining at this time.

Walleyes are a predator of young-of-the-year and yearling lake whitefish in Buck Lake. Since no walleyes were captured in any of the sampling gear employed in the five years of study on Pigeon Lake (Table XIV) and walleyes were last reported in the commercial harvest from Pigeon Lake in 1963/64, this species has been reduced in numbers or eliminated from Pigeon Lake. Buck Lake walleyes were documented as spawning in the lake in the spring on the same surficial lake sediments of boulders, sand and gravel, as lake whitefish utilize for spawning in the fall (Figure 6). Pigeon Lake with suitable, adequate spawning habitat for lake whitefish likely has adequate spawning habitat for walleyes.

A reduction in the size of the northern pike population in Pigeon Lake by the reduction in the spawning and recruitment habitat for this species likely has upset the ecological balance between predator and prey previously present in this lake. With a reduction in the numbers of the one predator, northern pike, the numbers of lake whitefish surviving to maturity has likely increased and the recruitment to this population increased yearly. Pigeon Lake lake whitefish feed on lake whitefish and burbot eggs (Figure 19). The Pigeon Lake lake whitefish likely fed on walleye eggs when available in the spring. Pigeon Lake lake whitefish feed on yellow perch y-o-y up to a total length of 27 mm. With a yearly increase in the recruitment to the lake whitefish population in Pigeon Lake and the resulting increase in intraspecific competition for food, the predation on walleye eggs and walleye y-o-y likely increased. The prey species likely contributed to the decline of this predator species in this ecosystem.

Walleye and northern pike populations in Pigeon Lake were likely reduced by the increased angling pressure that accompanied the increased summer cottage development on the lake. Angling in the summer was selective for the predator species, walleyes and northern pike, and non-selective for the prey species, lake whitefish and other forage fish. Lake whitefish are not available to the angler in these lakes during the open water period. Angling pressure for these predators on Buck Lake with limited cottage development was likely less than that of Pigeon Lake.

Increased interspecific competition for food by competitors of lake whitefish that also serve as prey to the predator species, northern pike and walleye, has likely contributed to the decrease in the growth rate of the Pigeon Lake lake whitefish population. Northern pike and walleyes in Buck Lake as well as preying on lake whitefish, are predators of yellow perch, burbot, troutperch, spottail shiners, sticklebacks and white suckers. With the exception of sticklebacks and the addition of emerald shiners, all the above prey species are present in Pigeon Lake and compete with lake whitefish for bottom fauna.

Pigeon Lake has a lower standing crop of bottom fauna than Buck Lake throughout the year (Figure 15). Both the increased number of lake whitefish and the increased number of other competitors for bottom fauna likely has caused an increased cropping of bottom fauna in Pigeon Lake in excess of that of Buck Lake. Increased competition for bottom fauna in Pigeon Lake in the winter months when invertebrate reproductive turnover is reduced has likely forced the total Pigeon Lake population on a diet of zooplankton (Figure 23). Reduced interspecific and intraspecific competition for bottom fauna by predators in Buck Lake likely allows

the surviving lake whitefish population to exist on a bottom fauna diet throughout the winter months. Not only do the y-o-y Pigeon Lake lake whitefish fall behind the growth rate of the Buck Lake y-o-y lake whitefish in the winter but the growth rate of the winter plankton feeding yearling and older Pigeon Lake lake whitefish is likely slower than that of the bottom feeding yearling and older Buck Lake fish. Yearling and older Pigeon Lake lake whitefish could also have a reduced growth rate during the summer months over that of the Buck Lake fish because of the lower standing crop of bottom fauna (Figure 15) available to the larger number of Pigeon Lake lake whitefish (Table XIX).

Growth in lake whitefish populations in Pigeon and Buck Lake occurs during the winter months (Table XIII). The increase in size with time of individuals in a population follows a sigmoid curve (Simpson, Roe and Lewontin, 1960). In fish, absolute growth, the average total size at each age, follows an indeterminate, sigmoid growth curve. Relative growth, the percentage increase in growth at each time interval, is largest in young fish passing through the greatest slope of the sigmoid curve (Rounsefell and Everhart, 1960). Differential growth of young-of-the-year fish in Pigeon and Buck Lake occurs during the winter months (Table XIII). Documentation of different growth rates of yearling and older fish in the winter months through sampling would be difficult since the relative growth rate of these fish is markedly lower and variation within the samples would mask the detection of growth.

If circuli are formed on scales of fish during the winter months, the fish must be growing. The distance from the focus to each annulus on fish scales is used to back-calculate the growth rate of populations of fish (Gerking, 1966). Circuli are laid down between

the annuli that are formed in the spring in temperate climates. If the distance between the annuli on scales is directly proportional to the growth of the fish, the number of and distance between circuli is related to growth. Circuli, although often incomplete, are laid down during the winter months. If circuli are formed during this period of time, the fish must be growing but the relative growth rate is much lower than that of the summer months when more favourable water temperatures and food supplies are prevalent.

II. Ecology of Lake Whitefish

Even though the growth rate of the Pigeon Lake population is much slower than that of the Buck Lake population (Table II), the age of maturity is similar in these two populations of fish (Figure 7). Both Budd and Cucin (1966) in studies on Lake Huron whitefish and Hart (1930) in studies on Lake Ontario whitefish reported these populations matured in their fifth year of life (four completed annuli) whereas Cucin and Regier (1962) reported male lake whitefish with four or more completed annuli and females with five or more completed annuli in Georgian Bay were mature. The majority of both Pigeon and Buck Lake male and female fish with four completed annuli were mature and all fish of both sexes in the samples with five completed annuli were mature. The studies of Kennedy (1953) and the present studies found both male and female fish maturing at the same age and size. Contrary to the findings of Miller (1947) on Pigeon Lake and consistent with those of Rybicki and Doan (MS 1966) on Lake Winnipeg, the differential growth rates of the Pigeon and Buck Lake whitefish populations in the present studies did not alter the age of maturity of these two populations of fish.

The sex ratio of samples of lake whitefish from the spawning beds in Pigeon Lake favoured females in four and males in five of the nine samples collected from September to February (Table V). The sex ratio of all fish sampled from collections made both on and off the known spawning beds approached a 50:50 sex ratio in both lakes. These findings are consistent with those of Miller (1956) in Pigeon Lake and Kennedy (1943) in Lake Opeongo, Algonquin Park, Ontario.

Selection would favour lake whitefish that spawn on a surficial lake sediment of boulders, gravel and sand in Pigeon and Buck lakes since the deposited eggs would be more protected from weather and less subject to predation than eggs released and exposed on a smooth bottom. Pigeon and Buck Lake lake whitefish concentrated on a surficial lake sediment of boulders, gravel and sand to spawn (Figure 6). Hart (1930) reported that lake whitefish in the Bay of Quinte, Lake Ontario spawned on a substrate of sand, gravel and boulders. Both Pigeon and Buck Lake lake whitefish fed on their own spawn but predation by Pigeon Lake whitefish was more prominent than that of the Buck Lake whitefish (Figure 19). Lake whitefish eggs were of minor prominence in the bottom fauna samples but of major importance as a food item during the whitefish spawning period. Bottom fauna samples were not taken on the spawning beds of Pigeon and Buck Lakes. Pigeon Lake fish were also noted as spawning on a surficial lake sediment of sand where the deposited eggs would be more accessible to the predators. Deposition of eggs on a smooth bottom likely accounts for the higher contribution of lake whitefish eggs in the diet of the Pigeon Lake fish than that of the Buck Lake fish. A lower standing crop of bottom fauna in Pigeon Lake (Figure 15) with a larger number of mature fish

per unit area (Table XIX) could account for the higher predation of Pigeon Lake fish on their own spawn and on spawn of burbot later in the winter than that of Buck Lake (Figure 18). Hart (1930) found that in the Bay of Quinte, Lake Ontario, yellow perch preyed extensively on accessible lake whitefish eggs and young-of-the-year but suckers did not feed extensively on lake whitefish eggs. The feeding habits of these two species on the spawning beds in Pigeon and Buck Lakes were not documented in the present studies.

Selection would favour lake whitefish that spawn in shallow waters. Eggs deposited in deeper waters would likely have a higher mortality rate through both the incubation period and at hatching. Price (1940) documented the increase in the mortality of lake whitefish eggs when incubated under higher temperatures (4.0°C+). Eggs deposited in deeper water would incubate at a higher temperature and have a shorter incubation period to hatching than eggs deposited and incubated in shallower, colder waters. Eggs from Pigeon and Buck Lake lake whitefish incubated at 4.0°C completed hatching while the two lakes were under ice cover whereas eggs from both lakes incubated at 2.0°C had modal hatching occurring after the ice left both lakes (Figure 10). Buck Lake lake whitefish eggs deposited in the lake were incubating under ice cover at a water temperature that approached 1.0°C.

Eggs deposited by lake whitefish in shallow water would have retarded incubation under low water temperatures through the winter months but have an accelerated rate of development in late winter. Water has a higher specific heat than land (Weber, White and Manning, 1957). The land warms up more rapidly in the spring than water. Water draining from the land into the lake melts the ice along the shore in

the spring. Eggs deposited in these shallow waters of the littoral zone would be subjected to increasing water temperatures, would have an increased rate of embryonic development and would likely hatch coincident with the breakup of ice on the lake in the spring and coincident with the beginning of zooplankton pulses that supply food for the emerging y-o-y lake whitefish.

A rising incubating water temperature in the spring in shallow water would decrease the length of the hatching period of the deposited eggs (Figure 10). Eggs deposited in deeper waters would incubate at temperatures higher than 2.0°C, would hatch under ice cover and would likely be subjected to higher mortality. Hart (1930) found lake whitefish in the Bay of Quinte, Lake Ontario spawning in water from 1 to 7 feet in depth (0.3 to 2.1 m).

A lake whitefish population that spawns over a wide range of water temperatures in open water and under ice cover would not likely suffer from reduced yearly recruitment or year-class failures due to adverse weather conditions in the fall or spring. A wide range in time when the young-of-the-year emerge from eggs would prevent large mortalities caused by strong, spring winds (Figure 10). Pigeon and Buck Lake lake whitefish spawned over a wide range of water temperatures (9.2 to 0.6°C) for a long period of time (4 months) in open water and under ice cover (Figure 8). Reduced recruitment or year-class failure to a lake whitefish population exposed to high winds at spawning (Miller, 1956) or at hatching (Christie, 1963) is unlikely in Pigeon and Buck lakes.

The ratio of the gonad weight to body weight of the slow growing population of lake whitefish does not differ from that of the faster

growing population. The slower growing population produces fewer but larger eggs than the faster growing population. The number of eggs produced per individual female is more closely controlled in a slower growing population than that of a faster growing population. The smaller sized, mature female Pigeon Lake lake whitefish produced similar sized gonads per unit body weight as that of the larger, mature, female, Buck Lake population (Figure 11). The Pigeon Lake fish had fewer but larger oviduct eggs (Table IX) than the Buck Lake samples. The larger Pigeon Lake oviduct eggs were consistently larger when fertilized and hardened than that of the smaller, Buck Lake fertilized and hardened eggs (Table X). No differences were observed between the size of hardened eggs and eyed eggs in the samples from the two lakes.

If incubating egg mortality in Pigeon Lake is comparable to that of Buck Lake, the reduction in the number of fish in Buck Lake surviving to maturity can be attributed to predation. Buck Lake has a higher standing crop of both bottom fauna (Figure 15) and zooplankton (Figure 21) than Pigeon Lake. Mortality from starvation would be less in Buck Lake than Pigeon Lake. Pigeon Lake lake whitefish produce an average of 11,112 eggs per female whereas Buck Lake fish produce an average of 49,114 eggs per female (Table VII). Pigeon Lake has an estimated population of mature fish that is about three times that of Buck Lake per unit area (Table XIX). Buck Lake likely has a higher yearly recruitment of lake whitefish per unit area than Pigeon Lake.

The size of the individuals in a spawning population determines the fecundity with the smaller sized individuals in a given population producing fewer eggs than larger sized individuals in a second population. Christie (1963) reported the fecundity of Lake Ontario whitefish to be

9,886±1,650 eggs/pound of fish (21,794±3,638 eggs/kg.). These values are intermediate between the lower value of the Pigeon Lake population and the higher value of the Buck Lake population (Table VII). The smaller sized females in the Pigeon Lake population not only produced fewer eggs but also larger eggs (Table IX) than the Buck Lake females. Fecundity and egg size could provide a useful index for comparing growth rates and condition factors of populations of lake whitefish.

The duration of the egg incubation period had a greater effect on the size of the hatching young-of-the-year fish than did the size of the egg under incubation. Eggs under incubation for a longer period of time tended to produce larger fish. Both the smaller Buck Lake lake whitefish eggs and the larger Pigeon Lake eggs yielded similar sized y-o-y on hatching under the same incubation period at 2.0°C (Table XI). Eggs from both populations of fish that incubated for longer periods tended to produce larger fish. Earlier hatching eggs produced y-o-y with noticeably larger yolk sacs. These fish remained on the bottom of the rearing containers relatively immobile for one to two weeks living off the yolk. When the yolk became depleted, the fish began to swim and utilize the available food supply of brine shrimp. The controlled incubation experimental temperature of 2.0°C more closely approached the 1.0°C egg incubating water temperature on the Buck Lake spawning beds than did the experimental, incubation temperature of 4.0°C. Gerking (1967) concluded from the works of several authors that larger fish produce larger eggs and larger emerging young-of-the-year. The experiments on lake whitefish eggs in the present studies do not support this conclusion but support that of Hart (1930) on lake whitefish who reported late hatching fry were longer than early hatching fry. At

a higher incubation temperature (2.0 to 4.0°C) the later hatching, larger Pigeon Lake eggs produced larger y-o-y than did either the earlier hatching Pigeon Lake eggs or the earlier or later hatching Buck Lake eggs. The larger eggs that likely had a larger yolk supply appear to produce larger y-o-y when incubated for a longer period of time under a temperature regime (2.0 to 4.0°C) that increased the rate of embryonic development.

The availability of food played a more important role in the feeding habits of Pigeon and Buck Lake lake whitefish populations than did selection for food items. Even though the standing crop of bottom fauna in Buck Lake was greater than that of Pigeon Lake from August to October (Figure 15), the Buck Lake population of yearling and older lake whitefish fed on plankton to a greater extent than did the Pigeon Lake population of yearling and older fish (Figure 23). At this time of year, the number of Cladocera increased in Buck Lake but not in Pigeon Lake (Figure 21). These Daphnia were carrying eggs at this time of year and were likely conspicuous to the feeding Buck Lake whitefish. Watson (1963) in studies on Heming Lake, Manitoba; Hart (1930) in studies on Bay of Quinte, Lake Ontario and Quadri (1961) in studies on Lac La Ronge, Saskatchewan also concluded that lake whitefish were opportunists with regard to feeding habits. The yearling and older lake whitefish in Pigeon Lake are likely forced onto a plankton diet during the winter months because of the low standing crop of bottom fauna (Figure 15) present in Pigeon Lake and the larger number of fish (Table XIX) competing for the available bottom fauna. A larger standing crop of bottom fauna (Figure 15) accompanied by a smaller number of lake whitefish (Table XIX) competing for bottom fauna enables the Buck Lake

population of yearling and older fish to remain on bottom fauna throughout the winter months.

Young-of-the-year lake whitefish emerging from eggs in the study lakes that ranged in total length from 15.2 to 18.9 mm fed on smaller invertebrates (immature *Diaptomus*, copepodids) and as their size increased fed on larger zooplankton (adult copepods, *Daphnia*). In the laboratory rearing experiments, newly hatched young-of-the-year fish fed only on unhatched brine shrimp eggs (0.267±0.077 mm) until they attained a larger size when they fed on the hatched brine shrimp (0.662±0.181 mm T.L.).

SUMMARY

1. Pigeon and Buck lakes have similar surficial lake sediments and morphometry but Buck Lake has a higher shore development ratio than Pigeon Lake.
2. The temperature regimes of both lakes are comparable.
3. The dissolved oxygen concentrations in both lakes are similar throughout the year and would not likely cause winter mortalities in either lake.
4. A reduction in the growth of the Pigeon Lake lake whitefish population has occurred since 1956 whereas the Buck Lake population has maintained a similar growth pattern over the same period of time.
5. Both populations of young-of-the-year fish feed on zooplankton during their first summer and winter but feed on bottom fauna during the second spring as yearling fish.
6. Divergence in growth between the two populations of lake whitefish occurs in young-of-the-year fish during the winter months.

7. Buck Lake has a higher standing crop of zooplankton than Pigeon Lake.
8. Buck Lake has a higher standing crop of bottom fauna than Pigeon Lake.
9. Pigeon Lake has an estimated mature population of lake whitefish that is about three times that of Buck Lake per unit area. The lake whitefish in both lakes are about four times more active in the open water period than under ice cover.
10. The slower growing Pigeon Lake lake whitefish population matures at the same age as the faster growing Buck Lake population.
11. Buck Lake lake whitefish have a higher length-weight ratio than Pigeon Lake fish.
12. Both populations of fish have the same number of gill rakers. The gill raker length to total length ratio is larger in the slower growing Pigeon Lake population.
13. Both populations of lake whitefish have about a four month spawning period and spawn over a wide range of water temperatures.
14. Peak spawning activity in Pigeon Lake occurs in open water (October) and under ice cover (December).
15. The incubation period for both Pigeon and Buck Lake lake whitefish eggs to the eyed egg stage, the occurrence of the first hatch and the occurrence of the first modal hatch are similar at a given egg incubation water temperature.
16. Both Pigeon and Buck Lake lake whitefish eggs hatched over similar periods of time when subjected to the same incubating water temperature regime. A lower incubating water temperature regime prolonged the incubation period and extended the duration of

hatching.

17. Mature Pigeon Lake female lake whitefish had similar ratios of gonad weight to body weight as mature Buck Lake fish. These ratios did not increase during the winter months after spawning but increased when the ice left the lakes in the spring and the lake water temperatures increased.

18. The fecundity of the smaller female lake whitefish from Pigeon Lake was lower than that of the larger females from Buck Lake.

19. The smaller sized females from Pigeon Lake produced larger eggs than the larger sized Buck Lake lake whitefish. All eggs in the gonads mature at the same time.

20. Pigeon Lake fertilized and hardened eggs and eyed eggs are larger than Buck Lake fertilized and hardened eggs and eyed eggs.

21. Pigeon and Buck Lake lake whitefish eggs incubated and hatched in the laboratory produced similar sized young-of-the-year fish.

22. Under the lower egg incubation water temperature regime, eggs incubated for longer periods of time produced larger emerging young-of-the-year fish.

23. Laboratory reared young-of-the-year lake whitefish from Pigeon and Buck Lakes had similar growth rates when reared for sixty-three days.

24. Walleye and brook sticklebacks were found in Buck Lake but were not present in the samples from Pigeon Lake. Emerald shiners were noted as present in Pigeon Lake but were not found in Buck Lake.

25. Since 1942, Buck Lake has produced, on the average, a higher yearly commercial harvest of lake whitefish per surface area

than Pigeon Lake.

26. Walleyes are predators of young-of-the-year and yearling lake whitefish in Buck Lake. Northern pike are predators of lake whitefish in Buck Lake, the size and age of the prey depends upon the size of the predator. Burbot prey on y-o-y and yearling lake whitefish.
27. Buck Lake has a greater density of rooted aquatic plants than Pigeon Lake.
28. Extensive cottage development around the perimeter of Pigeon Lake with the subsequent removal of rooted aquatic plants has reduced spawning and recruitment habitat for northern pike. Buck Lake with limited cottage development has extensive spawning and recruitment habitat for northern pike.
29. Walleyes are now scarce in or have been eliminated from Pigeon Lake. Walleyes are present in appreciable numbers in Buck Lake.
30. A reduction in the size of the predator population in the past twelve years has likely caused the decline in the growth rate of the lake whitefish population in Pigeon Lake. Maintenance of a sizeable predator population in Buck Lake likely accounts for the relatively stable growth pattern of this lake whitefish population over the same period of time.

LITERATURE CITED

Bird, C. D. 1968. Key to the aquatic molluscs found in the prairies and parklands of central Alberta. Dept. Biol. Univ. Calgary. 5 p.

Brooks, John Langdon. 1957. The systemics of North American Daphnia. Mem. Connecticut Acad. Arts Sci. 13. 180 p. Yale Univ. Press, New Haven, Connecticut.

Brynildson, Clifford. 1958. What's happening to northern pike spawning grounds? Wisc. Conserv. Bull. 23(5). 3 p.

Budd, John C. and D. Cucin. 1962. Exploitation of Canadian Lake Huron whitefish. Trans. Am. Fish. Soc. 91(2):223-224.

Christie, W. J. 1963. Effects of artificial propogation and weather on recruitment in the Lake Ontario whitefish fishery. J. Fish. Res. Bd. Canada. 20(3):597-646.

Clark, Clarence F. 1950. Observations on the spawning habits of northern pike, *Esox lucius*, in northwestern Ohio. Copeia, 1950. (4):285-287.

Cucin, Daniel and Henry A. Regier. 1966. Dynamics and exploitation of lake whitefish in southern Georgian Bay. J. Fish. Res. Bd. Canada. 23(2):221-274.

Davies, R. W. 1971. A key to freshwater Hirudinoidea of Canada. J. Fish. Res. Bd. Canada. 28(4):543-552.

Fabricus, Eric. 1950. Heterogenous stimulus summation in the release of spawning activities in fish. Inst. Freshw. Res. Drottningholm, Sweden. 31:57-99.

Fabricus, Eric and Karl-Jacob Gustafson. 1958. Some new observations of the spawning behavior of the pike, *Esox lucius* L. Inst. Freshw. Res. Drottningholm, Sweden. 39:23-54.

Fernald, Merritt Lyndon. 1950. Gray's manual of Botany. 8th Ed. Amer. Book Co., New York. 1632 p.

Fisher, Kenneth C. 1963. The formation and properties of the external membrane of the trout eggs. Trans. Royal Soc. Canada (IV):323-332.

Forney, John L. 1968. Production of young northern pike in a regulated marsh. New York Fish Game. 15(2):143-154.

Gerking, Shelby D. 1966. Annual growth cycle, growth potential, and growth compensation in the bluegill sunfish in northern Indiana lakes. J. Fish. Res. Bd. Canada. 23(12):1923-1956.

Gerking, Shelby D. (Ed). 1967. The biological basis of freshwater fish production. Blackwell Sci. Pub. Oxford. 495 p.

Hart, J. L. 1930. The spawning and early life history of the whitefish, *Coregonus clupeaformis*, in the Bay of Quinte, Ontario. Contr. Canadian Biol. Fish. 6(7):167-214. Univ. Toronto Press.

Hart, J. L. 1932. Studies of the whitefish (*Coregonus clupeaformis*) population of Shakespeare Island Lake, Ontario. Univ. Toronto Studies. Publ. Ont. Fish. Res. Lab. 42. Univ. Toronto Press. 28 p.

Higham, Joseph R. and William R. Nicholson. 1962. Sexual maturation and spawning of Atlantic menhaden. U. S. Dept. Int. Fish. Wildl. Serv. Bull. 63(2):255-271.

Kennedy, W. A. 1943. The whitefish, *Coregonus clupeaformis* (Mitchill), of Lake Opeongo, Algonquin Park, Ont. Publ. Ont. Fish. Res. Lab. Univ. Toronto Press. 51(62):22-66.

Kennedy, W. A. 1953. Growth, maturity, fecundity, and mortality in the relatively unexplcited whitefish, *Coregonus clupeaformis* in Great Slave Lake. J. Fish. Res. Bd. Canada. 10(9):413-441.

Kennedy, W. A. 1954. Tagging returns, age structures and fluctuations in abundance of Lake Winnipeg whitefish, 1931-1951. J. Fish. Res. Bd. Canada. XI(3):284-309.

Kennedy, W. A. 1963. Growth and mortality of whitefish in three unexploited lakes in northern Canada. J. Fish. Res. Bd. Canada. 20(2):265-272.

Kliewer, E. V. 1970. Gillraker variation and diet in lake whitefish *Coregonus clupeaformis* in Northern Manitoba. 147-165. (In) C. C. Lindsey and C. S. Wood (Ed) Biology of Coregonid fishes. Univ. Manitoba Press, Winnipeg. 559 p.

Lagler, Karl F. 1959. Freshwater fishery biology. Wm. C. Brown Co., Dubuque, Iowa. 421 p.

Lawler, G. H. 1965. Fluctuations in the success of year-class of whitefish populations with special reference to Lake Erie. J. Fish. Res. Bd. Canada. 22(5):1197-1227.

McCart, P. 1965. Growth and morphometry of four British Columbia populations of pigmy whitefish (*Prosopium coulteri*). J. Fish Res. Bd. Canada. 22(5):1229-1259.

Miller, Richard B. 1946. Effectiveness of a whitefish hatchery. J. Wildl. Mgt. 10(4):316-322.

Miller, Richard B. 1947. The effects of different intensities of fishing on the whitefish population of two Alberta lakes. J. Wildl. Mgt. 11(4):289-301.

Miller, Richard B. 1949. Problems of the optimum catch in small whitefish lakes. Biometrics. 5(1):14-26.

Miller, Richard B. 1952. The relative strength of whitefish year classes as affected by egg planting and weather. J. Wildl. Mgt. 16(1):39-50.

Miller, Richard B. 1956. The collapse and recovery of a small whitefish fishery. J. Fish. Res. Bd. Canada. 13(1):135-146.

Moss, E. H. 1959. Flora of Alberta. Univ. Toronto Press. 546 p.

Pennak, Robert W. 1953. Fresh-water invertebrates of the United States. Ronald Press, New York. 769 p.

Pennak, Robert W. 1963. Species identification of the fresh-water cyclopoid copepods of the United States. Trans. Am. Microscop. Soc. Bull. LXXXI(4):353-359.

Price, John W. 1940. Time-temperature relations in the incubation of the whitefish, *Coregonus clupeaformis* (Mitchill) J. Gen. Physiol. 23:449-468.

Qadri, S. U. 1961. Food and distribution of lake whitefish in Lac La Ronge, Saskatchewan. Trans. Am. Fish. Soc. 90(3):303-307.

Rounsefell, George A. and W. Harry Everhart. 1960. Fishery science - its methods and applications. John Wiley, New York. 444 p.

Rybicki, R. W. and K. H. Doan. MS1966. Changes in the population of Lake Winnipeg whitefish. Fish. Branch, Manitoba Dept. Mines Nat. Resources, Winnipeg. 16 p.

Simpson, George Gaylord, Anne Roe and Richard C. Lewontin. 1960. Quantitative Zoology. Harcourt, Brace Co., New York. 440 p.

Steel, Robert G. D. and James H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill, Toronto. 481 p.

Thompson, Richard B. 1959. Food of the squawfish *Ptychocheilus oregonensis* (Richardson) of the lower Columbia River. U. S. Dept. Int. Fish. Wildl. Serv. Fish. Bull. 158(60):43-58.

Usinger, Robert. 1963. Aquatic insects of California. Univ. California Press. 508 p.

Ward, Henry Baldwin and George Chandler Whipple. 1963. Freshwater Biology. 2nd Ed. W. T. Edmondson (Ed). John Wiley, New York. 1248 p.

Watson, W. H. F. 1963. Summer food of lake whitefish, *Coregonus clupeaformis* Mitchill from Heming Lake, Manitoba. J. Fish. Res. Bd. Canada. 20(2):279-286.

Weber, Robert L., Marsh W. White and Kenneth V. Manning. 1957. Physics for science and engineering. McGraw-Hill, Toronto. 618 p.

Welch, Paul S. 1948. Limnological methods. McGraw-Hill, Toronto. 381 p.

Wolf, Ken. 1970. White-spot disease of fish eggs and fry. U. S. Dept. Int. Bur. Sport Fish. Wildl. Div. Fish. Res. FDL-22:3 p.

APPENDICES

APPENDIX A

Mobile laboratory and 21 foot Starcraft boat used for sampling the populations of fish in Pigeon and Buck lakes. The four wheel drive vehicle with a power take-off winch carried an Alaskan camper that was hydraulically raised and lowered and contained a fish sampling table with a water supply and external drain, a Sartorius electric balance, a recording table, and lights for both 12 volt and 120 volt electrical systems and two 8,000 B.T.U. propane heaters.

APPENDIX A

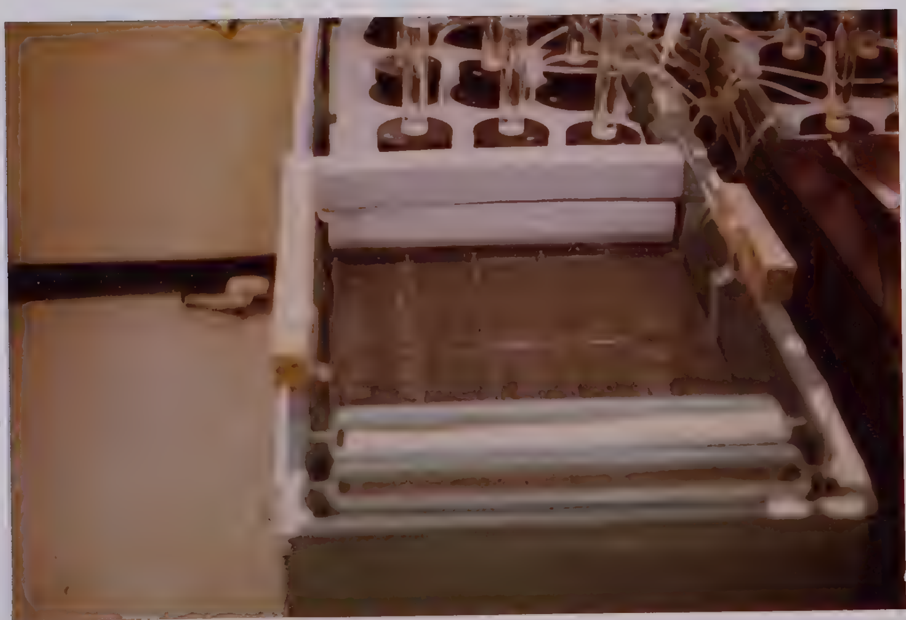
APPENDIX B

Recirculation troughs used in the lake whitefish egg incubation experiments. Both the jar culture (I) and trough culture (II) systems and the thermistemp controls and digitex thermometer at the head of the troughs are visible.

APPENDIX B

(i)

(ii)



APPENDIX C

Closed jar culture used in the lake whitefish egg incubation experiments. The compressed air/ozone line to the base of each jar used to roll the eggs and the reservoir of distilled water used to replenish water lost through evaporation are evident.

APPENDIX C

APPENDIX D

Egg picking and water filtration system used to filter the water in the closed system jars and remove dead eggs simultaneously. The black line is the vacuum line.

APPENDIX D

APPENDIX E

Jar culture system used to hatch brine shrimp eggs for feeding lake whitefish in culture experiments. The air lines to the styrofoam at the base of each jar mixed the saline water and eggs and the heater and water circulator (upper right of aquarium) controlled the temperature of the aquarium water.

APPENDIX E

APPENDIX F

Results of the chemical analysis of water samples from Pigeon and Buck Lake. All readings are in milligrams per litre unless otherwise specified. Samples were gathered at the surface of both lakes on August 24, 1971.

Analysis	Pigeon Lake	Buck Lake
Temp. at testing (^{o}C)	20.6	21.2
Turbidity (J.T.U.)	2.3	1.4
pH	8.1	8.3
Total organic carbon	14.0	15.0
Dissolved chloride	0.7	0.8
Dissolved copper	0.001	0.001
Dissolved fluoride	0.09	0.07
Dissolved iron	0.02	0.02
Dissolved lead	0.006	0.006
Dissolved manganese	0.014	0.014
Total nitrogen	1.21	1.15
Diss. nitrite, nitrate nitrogen	0.01	0.09
Dissolved orthophosphate	0.01	0.03
Dissolved inorganic phosphate	0.01	0.04
Total phosphate	0.07	0.08
Dissolved potassium	5.1	3.8
Specific conductance (μmho/cm.)	276	224
Total alkalinity ($CaCO_3$)	140	102
Total hardness ($CaCO_3$)	109	84.4
Dissolved calcium	27.3	25.4
Dissolved sulphate	3.3	8.7
Reactive silica (SiO_2)	3.6	11.4
Dissolved sodium	16.6	13.3
Dissolved zinc	0.002	0.002
Dissolved inorganic carbon	25.0	16.0
Dissolved aluminum	0.10	0.10
Dissolved barium	0.08	0.05
Dissolved cadmium	0.01	0.01
Total chromium	0.027	0.020
Dissolved colbalt	0.05	0.05
Dissolved lithium	0.007	0.003
Dissolved mercury	trace*	trace
Dissolved molybdenum	trace	0.06
Dissolved nickel	0.05	0.05
Dissolved strontium	0.30	0.21
Dissolved thallium	0.15	0.15

* less than 0.00005

APPENDIX G

Mean ($\bar{x}$) fork length (mm) of four age classes of fish from Miller (1956) and the 1970 and 1971 samples collected in the fall of each year from Pigeon and Buck Lake. The sum of the observations (ΣX), the sum of squares of the observations (ΣX^2) and the number of observations (n) in each partitioned group is presented.

Lake	Statistic	Number Annuli III	IV	V	VI
Pigeon (Miller, 1956)	$\bar{x}$	345.9	372.9	391.4	415.6
	ΣX	16258.6	54071.7	132301.5	52776.3
	ΣX^2	5627276.6	20168614.7	51795757.8	21934499.2
	n	47	145	338	127
Pigeon (1970)	$\bar{x}$	313.2	348.6	358.1	367.8
	ΣX	9396.0	10458.0	10742.0	11033.0
	ΣX^2	2958360.0	3651746.0	3853528.0	4064073.0
	n	30	30	30	30
Buck (1970)	$\bar{x}$	388.4	450.5	478.5	475.6
	ΣX	11653.0	13516.0	14355.0	14267.0
	ΣX^2	4533633.0	6123388.0	6900759.0	6804317.0
	n	30	30	30	30

APPENDIX H

Mean ($\bar{x}$) fork length (mm) of six age classes of Pigeon and Buck Lake lake whitefish sampled in the latter two weeks of September of 1971 and 1972. The sum of the observations (ΣX), the sum of squares of the observations (ΣX^2) and the number of observations (n) are presented.

Lake/Year	Statistic	Number Annuli					
		I	II	III	IV	V	VI
Pigeon/70	$\bar{x}$	189.73	248.80	313.20	348.60	358.17	367.77
	ΣX	5692.0	7464.0	9396.0	10458.0	10742.0	11033.0
	ΣX^2	1082740.0	1863226.0	2958360.0	3651746.0	3853528.0	4064073.0
	n	30	30	30	30	30	30
Pigeon/71	$\bar{x}$	183.40	244.71	328.27	357.27	373.17	379.00
	ΣX	5502.0	6607.0	9848.0	10718.0	11195.0	11370.0
	ΣX^2	1011178.0	1641833.0	3253236.0	3843094.0	4183865.0	4314146.0
	n	30	27	30	30	30	30
Buck/70	$\bar{x}$	213.57	345.0	388.43	450.53	478.50	475.57
	ΣX	6407.0	10350.0	11653.0	13516.0	14355.0	14267.0
	ΣX^2	1380431.0	3615078.0	4533633.0	6123388.0	6900759.0	6804317.0
	n	30	30	30	30	30	30
Buck/71	$\bar{x}$	232.67	313.20	385.07	441.40	483.03	502.30
	ΣX	6980.0	9396.0	11552.0	13242.0	14491.0	15069.0
	ΣX^2	1640074.0	2955014.0	4454492.0	5851542.0	7020767.0	7584211.0
	n	30	30	30	30	30	30

APPENDIX I

Mean ($\bar{x}$) total length (mm) and the range of the samples of Pigeon and Buck Lake lake whitefish used for morphometric and meristic comparisons. The mean gill raker length to total length X 100 and the mean gill raker number of the two samples is presented. The sum of the observations (ΣX), the sum of squares of the observations (ΣX^2) and the number of observations (n) of each sample are presented.

Lake	Statistic	Total Length	Gill Raker Length X 100 / Total Length	Gill Raker Number
Pigeon	Range	355-445	5.4-9.6	23-31
	$\bar{x}$	399.74	1.8232	27.08
	ΣX	19987.0	91.1600	1354.0
	ΣX^2	8014641.0	168.2944	37050.0
	n	50	50	50
Buck	Range	388-640	7.2-11.3	25-30
	$\bar{x}$	504.98	1.6770	27.36
	ΣX	25249.0	83.8500	1368.0
	ΣX^2	12947751.0	141.7321	37520.0
	n	50	50	50

APPENDIX J

Mean ($\bar{x}$) oviduct egg size (mm) of the means of thirty samples of fifty eggs each from each of three locations of the left gonad of Pigeon Lake mature lake whitefish sampled in both 1969 and 1970 and Buck Lake fish sampled in 1970. The sum of the observed means (ΣX), the sum of squares of the observed means (ΣX^2) and the number of means (n) used in the calculations are presented.

Statistic	Pigeon Lake						Buck Lake		
	1969			1970			1970		
	Ant.	Mid.	Post.	Ant.	Mid.	Post.	Ant.	Mid.	Post.
$\bar{x}$	1.8500	1.8566	1.8623	1.8713	1.8840	1.8726	1.7726	1.7580	1.7733
ΣX	55.50	55.70	55.87	56.14	56.52	56.18	53.18	52.74	53.20
ΣX^2	103.2052	103.9356	104.6781	105.2100	106.6464	105.3852	94.5932	93.0668	94.6624
n	30	30	30	30	30	30	30	30	30

APPENDIX K

Mean ($\bar{x}$) of the length (mm) of three samples of fifty eggs each from Pigeon and Buck Lake lake whitefish measured at the hardened egg stage and the eyed egg stage after incubating in Pigeon and Buck Lake water. The sums of the observations (ΣX), the sum of squares of the observations (ΣX^2), the number of observations (n) and the average size of an egg in each sample ($\bar{x}_e$) are presented.

Development Stage	Statistic	Pigeon Lake Eggs		Buck Lake Eggs	
		Pigeon Lake Water	Buck Lake Water	Pigeon Lake Water	Buck Lake Water
Hardened	$\bar{x}$	136.00	134.33	122.00	122.33
	ΣX	408.0	403.0	366.0	367.0
	ΣX^2	55494.0	54137.0	44678.0	44897.0
	n	3	3	3	3
	$\bar{x}_e$	2.72	2.69	2.44	2.45
Eyed	$\bar{x}$	137.67	131.33	122.00	123.0
	ΣX	821.0	394.0	366.0	736.0
	ΣX^2	112363.0	51750.0	44654.0	90290.0
	n	3	3	3	3
	$\bar{x}_e$	2.75	2.63	2.44	2.46

APPENDIX L

Mean ($\bar{x}$) total length (mm) of Pigeon and Buck Lake lake whitefish reared under similar photoperiod, diet and water temperature and sampled at two different rearing periods. The sum of the observations (ΣX), the sum of squares of the observations (ΣX^2) and the number of observations (n) in each sample are presented.

Statistic	Pigeon Lake		Buck Lake	
	57 Days	60 to 63 Days	57 Days	60 to 63 Days
$\bar{x}$	31.53	31.50	31.33	32.00
ΣX	946.0	945.0	940.0	960.0
ΣX^2	29920.0	29865.0	29670.0	30784.0
n	30	30	30	30

APPENDIX M

Mean ($\bar{x}$) fork length (mm) of young-of-the-year (0+) and yearling (1+) lake whitefish samples collected from August, 1971 to June, 1972. The sum of squares (ΣX^2), sum of the observations (ΣX), mean ($\bar{x}$), number of observations (n) and range of each sample is presented.

LAKE	DATE	AGE	STATISTIC				
			$\bar{x}$	ΣX	ΣX^2	n	Range
Pigeon	Aug 19/71	0+	89.61	3226.0	289710.0	36	80- 98
	Sept 8/71	0+	103.00	721.0	74315.0	7	97-106
	Dec 17/71	0+	119.46	5734.0	686694.0	48	108-129
	June 6/72	1+	131.80	5799.0	766617.0	44	115-150
Buck	Aug 18/71	0+	91.15	3737.0	341535.0	41	80-100
	Sept 1/71	0+	102.70	7292.0	750348.0	71	91-115
	Dec 30/71	0+	129.00	387.0	50145.0	3	118-139
	May 31/72	1+	143.03	5435.0	779215.0	28	130-161

cont.

Lake	Sediment	Hirudinea: *Erpobdella punctata*	Hirudinea: *Glossiphonia complanata*	Hirudinea: *Hellobdella stagnalis*	Hirudinea: *Nephelopsis obscura*	Trichoptera: *Helicopsyche borealis*	Trichoptera: *Molanna sp.*	Trichoptera: *Oecetis sp.*	Trichoptera: *Mytacides interjecta*	Trichoptera: *Lepidostoma sp.*	Trichoptera: *Ochrotrichia sp.*	Trichoptera: *Phryganea cinerea*	Trichoptera: *Polycentropus sp.*	Miscellaneous: Oligochaeta	Miscellaneous: Chaoboridae	Miscellaneous: Corixidae	Miscellaneous: Hydra	Miscellaneous: Hydracarina	Miscellaneous: Ostracoda	Miscellaneous: Nematoda	Miscellaneous: Ceratopogonidae	Miscellaneous: Fish Eggs	Miscellaneous: Coleoptera
Pigeon	Sand	0	0	6	1	0	7	28	6	1	0	2	2	85	0	3	2	33	0	119	152	5	0
	Silt	0	0	1	0	0	0	0	2	0	0	0	0	142	1	0	0	9	12	11	0	0	0
	Rubble	0	1	10	1	3	15	10	35	0	0	0	2	71	0	2	0	7	0	4	11	3	2
Buck	Sand	2	4	75	3	13	87	86	159	17	1	11	3	1877	16	2	0	4	0	97	352	0	0
	Silt	0	0	58	0	1	0	0	0	0	0	0	1	565	670	0	0	56	0	24	4	0	0
	Rubble	0	2	47	9	116	21	29	48	24	9	26	138	32	0	0	8	1	0	0	3	0	0

APPENDIX N

Total number of invertebrates in the bottom samples taken in three surficial lake sediments of both Pigeon Lake and Buck Lake over a period of one year.

Lake	Sediment	Amphipoda		Ephemeroptera				Gastropoda							Pelecypoda		Tendipedidae	
		Hyalella azteca	*Gammarus lacustris*	*Ameletus sp.*	*Caenis sp.*	*Ephemera sp.*	*Paraleptophlebia sp.*	*Fossoria dalli*	*Helisoma anceps*	*Lymnaea stagnalis*	*Physa anatina*	*Promenetus exacuous*	*Valvata lesisi*	*Valvata tricarinata*	*Sphaerium striatum*	*Sphaerium sulcatum*	*Tendipes sp.*	Others
Pigeon	Sand	1868	0	0	41	13	7	2	0	15	1	0	0	2	138	0	0	787
	Silt	2	0	0	0	0	0	0	0	0	0	1	2	0	54	3	1233	612
	Rubble	1002	0	0	5	1	5	5	0	8	2	4	0	3	15	0	1	1194
Buck	Sand	1253	9	2	53	0	1	7	15	205	0	4	4	130	791	102	150	2845
	Silt	23	1	0	0	0	0	0	0	0	0	1	31	7	444	5	683	1495
	Rubble	640	148	0	65	10	184	14	1	5	6	106	18	2	29	1	1	2903

cont.